Final Draft

Columbia River Estuary Recovery Plan Module

NOAA Fisheries

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NOTE TO READERS:

This draft *Columbia River Estuary Recovery Plan Module* will be the basis of estuary recovery actions for Endangered Species Act-listed salmon and steelhead in the Columbia River Basin. The module will be incorporated by reference into recovery plans for listed Columbia Basin salmon evolutionarily significant units (ESUs) and steelhead distinct population segments (DPSs). It is important to have a unified set of actions for the Columbia River estuary to address the needs of all listed Columbia Basin ESUs and DPSs. If you have questions or comments on the module at this time, please contact Cathy Tortorici at the National Marine Fisheries Service Northwest Regional Office (503-231-6268 or cathy.tortorici@noaa.gov). The estuary module will be formally made available for public comment during the public comment period for the proposed *Lower Columbia River ESA Recovery Plan* (this comment period is expected to occur in the spring of 2007, and will be announced in the *Federal Register*).

This draft *Columbia River Estuary Recovery Plan Module* was prepared by the Lower Columbia River Estuary Partnership under contract to NOAA Fisheries.

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Acronyms

BiOp	Biological Opinion
BMPs	best management practices
cfs	cubic feet per second
CRE	Columbia River estuary
CSMEP	Collaborative Systemwide Monitoring and Evaluation Project
DDT	dichlorodiphenyltricholoroethane
DPS	distinct population segment
EDT	Ecosystem Diagnosis and Treatment
ENSO	El Niño/Southern Oscillation
ESA	Endangered Species Act
ERME	estuary research, monitoring, and evaluation
ESU	evolutionarily significant unit
ETM	estuarine turbidity maximum
FCRPS	Federal Columbia River Power System
GIS	geographic information system
HUC	hydrologic unit code
ISAP	Independent Science Advisory Panel
ISRP	Independent Science Review Panel
LCFRB	Lower Columbia Fish Recovery Board
LCRANS	Lower Columbia River Aquatic Nonindigenous Species Survey
LCREP	Lower Columbia River Estuary Partnership
LIDAR	Light Detection and Ranging
MR&E	monitoring, research, and evaluation
NASQAN	National Stream Quality Accounting Network
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PDO	Pacific Decadel Oscillation
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
RM	river mile
WDF	Washington Department of Fisheries

Glossary

Accretion: The accumulation of sediment deposited by natural fluid flow processes.

Alevins: Salmonids at the life stage between egg and fry.

Bathymetry: The measure of the depths of oceans, seas, or other large bodies of water.

Beach erosion: The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

Beach nourishment: The process of replenishing a beach by artificial means, such as through deposition of dredged materials; also called beach replenishment or beach feeding.

Buffer area: A parcel or strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from upland impacts, to provide habitat for wildlife.

Continental shelf: The zone bordering a continent extending from the line of permanent immersion to the depth (usually about 100 to 200 meters) at which there is a marked or steep descent toward greater depths.

Delta: An alluvial deposit, usually triangular, at the mouth of a river. It is normally built up only where there is no tidal or current action capable of removing the sediment as fast as it is deposited.

Detritus: A loose mixture of organic material (dead plants and animals) and inorganic material (rock fragments) that results directly from disintegration of the material.

Dikes: Earthen walls constructed to contain water; sometimes constructed around dredged material disposal sites but more commonly constructed as flood protection.

Dredging: The removal or redistribution of sediments from a watercourse.

Ecosystem: A community of organisms in a given area together with their physical environment and its characteristic climate.

El Niño/Southern Oscillation: A shorter term climate effect that alternates between cold and warm phases approximately every 3 to 7 years; is associated with a warm-water current that periodically flows southward along the coast of Ecuador, and the southern oscillation in the atmosphere; affects climatic and ocean conditions throughout the Pacific region.

Emergent marsh: A wet, springy peatland that occurs along the edges of lakes and streams and is covered by grass-like sedges and fed by minerals washing in from surrounding lands.

Estuarine turbidity maximum (ETM): A circulation phenomenon in an estuary that traps particles and promotes biochemical, microbial, and ecological processes that sustain an important pathway in the estuary’s food web.

Estuary: A semi-enclosed coastal body of water with a free connection to the open ocean in which sea water is diluted with runoff from the land.

Exotic species: A non-native plant or animal deliberately or accidentally introduced into a habitat.

Fingerling: A juvenile salmonid less than 1 year old.

Floodplain: A flat tract of land bordering a river, mainly in its lower reaches, and consisting of alluvium deposited by the river during flooding.

Fluvial: Involving running water; usually pertains to stream processes.

Forested wetlands: Wetlands that occur in palustrine and estuarine areas and possess an over story of trees, an understory of young trees or shrubs, and a herbaceous layer.

Freshet: High stream flow caused by rains or snowmelt and resulting in the sudden influx of a large volume of freshwater in the estuary.

Fry: Juvenile salmonids that have absorbed their egg sac.

Genetic diversity: Variation at the level of individual genes (polymorphism); provides a mechanism for populations to adapt to their ever-changing environment.

Habitat: The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal; the place where an organism naturally lives.

Habitat capacity: A category of habitat assessment metrics, including "habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality" (Fresh et al. 2005).

Habitat connectivity: A measure of how connected or spatially continuous habitats occur in a larger ecosystem.

Habitat opportunity: A category of habitat assessment metrics that evaluate the capability of juvenile salmon to access and benefit from the habitat's capacity (Fresh et al. 2005).

Limiting factor: Physical, chemical, or biological features that impede species and their independent populations from reaching viability status.

Littoral: Of, relating to, or situated or growing on or near a shore; especially of the sea.

Littoral current: A current running parallel to the beach and generally caused by waves striking the shore at an angle.

Macrodetritus: Dead or dying matter from a plant or animal that is visible to the unaided eye; usually larger than 1 to 2 mm in diameter.

Microdetritus: Dead or dying matter from a plant or animal; usually smaller than 1 to 2 mm in diameter.

Navigational channels: Channels in estuaries and other water bodies that are created, deepened, and maintained by dredging to enable vessels to navigate safely between, into and out of ports, harbors, and marinas without running aground.

Nearshore: An indefinite zone extending seaward from the shoreline well beyond the breaker zone.

Ocean-type: Of or relating to salmonid juveniles that enter the estuary as fry or fingerlings and stay in the estuary for weeks or months before entering the ocean; examples are chum and subyearling chinook.

Oligohaline: Of or relating to water having low salinity.

Overbank flooding: Out-of-bank flooding resulting from flow events that exceed the bankfull.

Pacific Decadel Oscillation: A longer term climate effect that alternates between cold and warm phases approximately every 30 years.

Pelagic: Pertaining to the open ocean.

Pinnipeds: Seals, sea lions, and walruses that belong to the taxonomic suborder called Pinnipedia, or the "fin-footed." Pinnipeds are carnivorous aquatic mammals that use flippers for movement on land and in the water. The pinnipeds referred to in this document are Pacific harbor seals, California sea lions, and Stellar sea lions.

Pier: A structure, usually of open construction, extending out into the water from the shore, to serve as a landing place, recreational facility, etc., rather than to afford coastal protection.

Plume: The layer of Columbia River water in the nearshore Pacific Ocean.

Polychlorinated biphenyls (PCBs): A group of synthetic, toxic industrial chemical compounds that are chemically inert and not biodegradable; they once were used in making paint and electrical transformers.

Polycyclic aromatic hydrocarbons (PAHs): A group of more than 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat.

Population: A distinct breeding unit of a species that exhibits similar life history strategies.

Redds: Spawning nests used by trout and salmon.

Revetment: A facing of stone, concrete, etc., to protect an embankment or shore structure from erosion by wave action or currents.

Salmonid population viability: Measure of the status of anadromous salmonids that uses four performance criteria: abundance, productivity, spatial distribution, and diversity.

Salmonid: Any member of the family Salmonidae, which includes the salmon, trout, char, whitefishes, and grayling of North America.

Sand: An unconsolidated mixture of inorganic soil (possibly including disintegrated shells and coral) consisting of small but easily distinguishable grains ranging in size from about 0.062 mm to 2.0 mm.

Sediment: Material in suspension in water or recently deposited from suspension; in the plural, all kinds of deposits from the waters of streams, lakes, or seas.

Smolts: Juvenile salmonids that have left their natal stream and are headed downriver toward the ocean.

Stream-type: Of or relating to salmonid juveniles that rear in freshwater for a year or more before entering the ocean.

Threat: A human action or natural event that causes or contributes to limiting factors; threats may be caused by past, present, or future actions or events.

Tide: The periodic rising and falling of the water that results from gravitational attraction of the moon and sun acting on the rotating earth.

Turbidity: A condition in bodies of water where high sediment loads cause clouding of the water to varying extents; turbidity is an optical phenomenon and does not necessarily have a direct linear relationship to particulate concentration.

Viable: Capable of growing or developing.

Executive Summary

What is the Estuary Recovery Module?

This estuary recovery module is one element of a larger planning effort led by the National Marine Fisheries Service (NMFS, also known as NOAA Fisheries) to develop recovery plans for Endangered Species Act-listed salmon and steelhead trout in the Columbia River basin. Recovery plans are being developed for each of the 13 evolutionarily significant units (ESUs) in the Columbia.[1] Figure ES-1 shows the 13 listed ESUs in the Columbia River basin grouped by region. The regions include the Lower Columbia, Upper Willamette, Middle Columbia, Snake, and Upper Columbia River ESUs. Within each of the regions, the ESUs have unique geographical boundaries that are based on similarities among populations.

This estuary recovery module is one of several modules intended to complement recovery plans by identifying actions that can improve the survival of salmon and steelhead in conjunction with efforts to improve tributary habitats and reduce other threats. Separate modules address harvest, hatcheries, and hydroelectricity production. Additional refinements to this module are anticipated in 2006 as a result of public and stakeholder involvement. A final draft is anticipated in December 2006.

The goal of this estuary module is to identify and prioritize management actions that, if implemented, would reduce the impacts of the limiting factors that salmon and steelhead encounter during migration and rearing in the estuary and plume ecosystems. To accomplish this, changes in the physical, biological, or chemical conditions in the estuary are reviewed for their potential to affect salmon and steelhead. Then, the underlying causes of limiting factors are identified and prioritized based on the significance of the limiting factor and each cause’s contribution to one or more limiting factors. These causes are referred to as threats and can be either human or environmental in origin. Finally, management actions are identified that are intended to reduce the threats and increase the survival potential of salmon and steelhead during estuarine rearing and migration. Costs are developed for each of the actions using an estimated level of effort to implement actions.

This estuary recovery plan module is intended to help answer questions about the degree to which the estuary and plume can contribute to salmon and steelhead recovery efforts throughout the Columbia River basin. The state of the science surrounding the estuary and plume is such that quantitative answers to questions about estuarine ecology are not necessarily available at this time. This is true in part because of the complexity of the ecological processes in the estuary and plume. However, it is also true because the Columbia River estuary and plume are only now being studied at a level of detail that allows knowledge about this portion of the Columbia River ecosystem to be integrated into

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[1] NOAA Fisheries has revised its species determinations for West Coast steelhead under the Endangered Species Act (ESA), delineating steelhead-only “distinct population segments” (DPSs). The former steelhead ESUs included both anadromous steelhead trout and resident, non-anadromous rainbow trout, but NOAA Fisheries listed only the anadromous steelhead. The steelhead DPS does not include rainbow trout, which are under the jurisdiction of the U.S. Fish and Wildlife Service. In January 2006, NOAA Fisheries listed five Columbia River basin steelhead DPSs as threatened (71 FR 834). To avoid confusion, references to ESUs in this estuary recovery plan module imply the steelhead DPSs as well.

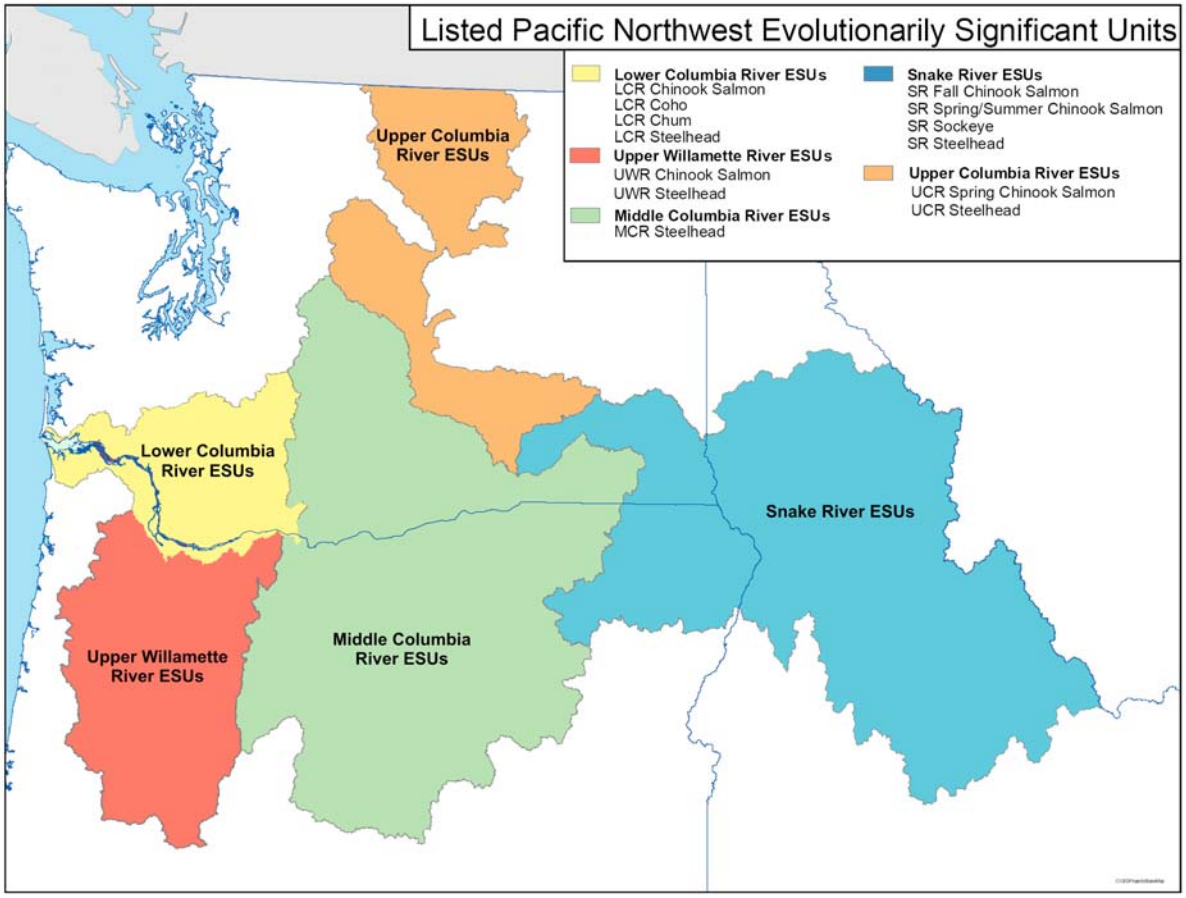

FIGURE ES-1
Listed Pacific Northwest ESUs

the understanding of life history patterns that have been well documented in the upstream portions of the basin.

This estuary recovery plan module is a synthesis of diverse literature sources and the direct input of estuary scientists. Several key documents were used extensively as a platform for the module because of the similarities in their purpose and content. One of those documents is the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan," which, along with its supplement, was developed by the Lower Columbia River Estuary Partnership for the Northwest Power and Conservation Council's *Columbia River Basin Fish and Wildlife Program* (Northwest Power and Conservation Council 2004). In 2005 NOAA/NMFS's Northwest Fisheries Science Center produced two important technical memoranda for the estuary: *Salmon at River's End* (Bottom et al. 2005) and *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead* (Fresh et al. 2005). These two memoranda were also used extensively. Other sources were consulted as well, including many primary sources. Area experts from NOAA/NMFS's Northwest Fisheries Science Center, other NMFS staff, Lower Columbia River Estuary Partnership staff, and the Lower Columbia Fish Recovery Board provided input and advice on scoring and evaluation processes.

Why Are the Estuary and Plume Important?

The Columbia River estuary and plume represent one of three major stages in the life cycle of salmon and steelhead. In tributaries, adults spawn and juveniles rear in freshwater. In the ocean, juveniles grow to adults as they forage in food-rich environments. The estuary is where juveniles and adults undergo vast physiological changes needed to transition to and from saltwater. In addition, a properly functioning estuary provides high growth opportunities and refugia from predators.

But why are the estuary and plume so important? The answer lies in the very reason that salmonids grew in numbers to an estimated 16 million over the past 4,000 years. Salmon and steelhead were successful because they exploited every habitat niche available to them. They did this by employing a variety of strategies that allowed them to use many diverse habitats across a wide geographic space. In fact, the distribution of salmon and steelhead historically spanned thousands of river miles throughout the basin.

If this were not remarkable enough, salmon and steelhead's traits allowed them to use habitats at varying times, and this is why the estuary and plume are so important. Every downstream-migrating juvenile salmon or steelhead must use the habitats of the estuary to complete its life cycle. If the progeny of the 16 million adult salmon and steelhead that historically made use of the estuary had converged on the estuary at one time, there likely would not have been enough habitat and food to sustain them. So they developed strategies to enter the estuary at different times, at different sizes, using unique habitats. In fact, it has been hypothesized that each individual population's use of estuarine habitats is discrete in terms of time and location of use. The implication of this for the estuary and plume today is that the area's habitats must be available through time and space and at sufficient quantities to support more than 150 distinct salmon and steelhead populations, which represent 13 ESUs that use many diverse life history strategies.

The number of adult salmon and steelhead that return to the Columbia River basin each year varies, but in recent years returns have been approximately 1.7 million. To achieve these returns, approximately 200 million juveniles are produced in tributary or mainstem gravels of the river or in hatchery ponds. After losses totaling approximately 20 percent in the tributaries, about 168 million juveniles enter the estuary (Ferguson 2006b). Threats in the estuary, plume, nearshore, and ocean account for the remaining mortality losses. Understanding the extent to which the estuary and plume contribute to this loss is essential to the ultimate recovery of salmon and steelhead ESUs throughout the basin.

What Is the Condition of the Estuary Now?

Flows, Dikes and Filling, Sediment, and Temperature

The estuary and plume are considerably degraded compared to only 200 years ago. In terms of absolute size, the estuary tidal prism is about 20 percent smaller than it was when Lewis and Clark camped along the Columbia's shore (Northwest Power and Conservation Council 2004). This reduction in estuary size is due mostly to dike and filling practices used to convert the floodplain to agricultural, industrial, commercial, and residential uses. Instream flows entering the estuary also have changed dramatically—there has been a 44 percent decrease in spring freshets or floods, and the annual timing, magnitude, and duration of flows no longer resemble those of the historical hydrograph in the Columbia River (Jay and

Kukulka 2002). Changes to the hydrograph are attributed to flow regulation by the hydrosystem, water withdrawal for irrigation and water supplies, and climate fluctuations.

Flow alterations and dike and filling practices are significant to salmon and steelhead in several ways. Historically, vegetated wetlands within the floodplain supplied the estuary with its base-level food source: macrodetritus. The near elimination of overbank events and the separation of the river from its floodplain have altered the food web by reducing macrodetrital inputs by approximately 84 percent (Bottom et al. 2005). At the same time, phytoplankton detrital sources from upstream reservoirs now dominate the base of the food chain. The substitution of food sources likely has profound effects on the estuary ecosystem. In addition, access to and use of floodplain habitats by ocean-type ESUs (salmonids that typically rear for a shorter time in tributaries and a longer time in the estuary) have been severely compromised through alterations in the presence and availability of these critical habitats.

The timing, magnitude, and duration of flows also have important ramifications to in-channel habitat availability and connectivity. Sand and gravel transport along the river bottom is highly correlated to flow. By reducing the magnitude and duration of flows, erosion and accretion processes no longer function as they have for thousands of years. This may have far-reaching consequences to the estuary, plume, and nearshore lands north and south of the river’s mouth. At the same time, upstream dams have prevented sand and gravel from entering the estuary, while dredging activities have exported sand and gravel out of the estuary. Studies have shown that sand and gravel are exported from the estuary at a rate three times higher than that at which they enter the estuary. The full impact of these changes is unknown; however, sediment transport is a primary habitat-shaping force that determines the type and location of habitats distributed in the estuary and plume. Recent bathymetry modeling efforts and new research on juvenile salmonid use of estuary habitats will help characterize juvenile mortality in the near future. Decreases in sediments also improve water clarity and increase the effectiveness of predators that consume juvenile and adult salmon and steelhead.

Elevated temperatures of water entering the estuary are a threat to salmon and steelhead. Summer water temperatures entering the estuary are on average 4 degrees warmer today than they were in 1938 (Lower Columbia Fish Recovery Board 2004). The upper range for cold-water fish, including salmon and steelhead, is about 20° to 24° Celsius. Temperatures exceeding this threshold have been occurring earlier in the year and more frequently since 1938 (as measured at Bonneville Dam). Degradation of tributary riparian habitat caused by forest, residential, commercial, and industrial practices, as well as reservoir heating, is responsible for increased temperatures.

Water Quality

Water quality in the estuary and plume has been degraded by human practices from within the estuary and also from upstream sources. An important indicator of water quality degradation found in the estuary is the presence of toxic contaminants. A recent study of contaminant impacts on juvenile salmon estimated delayed disease-induced mortalities of 3 and 18 percent as a result of contaminant stressors for residencies in the Columbia River estuary of 30 to 120 days, respectively (Loge et al. 2005). If this estimate is accurate, threats from contaminants may exceed those from Caspian tern predation.

Many contaminants are found in the estuary and plume. Some of them are water-soluble agricultural pesticides and fertilizers such as simazine, atrazine, and diazinon. Industrial contaminants include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Concentrations of these substances, and others, are found throughout the estuary, sometimes near cities and other times in bays and shallows where low-velocity flows allow suspended contaminants to settle. Salmon and steelhead are affected by contaminants through short-term exposure to lethal substances or through longer exposures to chemicals that accumulate over time and magnify through the food chain. Ocean-type ESUs are more susceptible to bioaccumulation than stream-type ESUs; however, both are equally vulnerable to acute exposures (stream-type ESUs are those ESUs that typically spend longer periods in tributaries and less time in the estuary).

Food Web and Species Interactions

The Columbia River estuary represents a distinct ecosystem that is a unique expression of biological and physical interactions. As physical and biological changes occur in the estuary, the ecosystem responds to those changes. There is general agreement that the estuary ecosystem is degraded and no longer provides the same level of support to native species assemblages that it did historically. Unfortunately, this field of research is perhaps the least understood, and its impact on salmon and steelhead is not well documented or studied.

Limiting factors related to the food web and species interactions can be thought of as the product of all the threats to salmon and steelhead in the estuary. Some examples are easy to understand, but others are subtle and far-reaching. Caspian terns are a good example of an ecosystem shift that is easy to understand. New islands formed through the disposal of dredged materials attracted terns away from their traditional habitats, which may be being degraded. Reduced sediment in the river increased terns' efficiency in capturing steelhead juveniles migrating to saltwater at the same time that the birds need additional food for their broods. The result is a predator/prey shift in the estuary that has increased mortality for steelhead juveniles. Double-crested cormorants also prey on juvenile salmonids, in similar numbers as terns.

Other shifts in the ecosystem are more complex, and it can be difficult to understand whether or how they affect salmon and steelhead. For example, the shift from macrodetritus-based primary plant production to phytoplankton production strikes at the most elemental level of the food chain in the estuary; however, what this means to salmon and steelhead—or, for that matter, to the entire estuary ecosystem—is unknown. The introduction of exotic species is another poorly understood ecosystem alteration. Examples of exotic species thriving in the estuary include 21 new invertebrates, plant species like Eurasian water milfoil, and exotic fish like shad. Shad in particular, because of the sheer tonnage of their biomass, undoubtedly play a large role in the degradation of the estuary ecosystem.

Other Threats

The estuary also is influenced by a number of physical structures that contribute to the estuary's overall degradation, but the extent of their impacts to salmon and steelhead is poorly understood. Structures in the estuary number in the thousands. Over-water and instream structures alter river circulation patterns, sediment deposition, and light penetration, and they form microhabitats that often benefit predators. Examples of structures include jetties, pile dikes, rafts, docks, breakwaters, bulkheads, revetments, groins, and ramps.

Ship wake stranding is an example of another threat to salmon and steelhead in the estuary. A study in 1977 by the Washington Department of Fisheries estimated that more than 150,000 juvenile salmonids, mostly chinook, were stranded on five test sites as a result of ship bow waves striking shorelines (Bauersfeld 1977). Additional studies since the Bauersfeld study have not documented the same level of mortality. Results from a new study by the University of Washington and the Portland District of the U.S. Army Corps of Engineers and future Light Detection and Radar (LIDAR) analysis may help characterize this threat in the near future. This threat is most detrimental to ocean-type juvenile fry that are less than 60 millimeters long and rear inches from shore.

What Can We Do to Improve Salmon and Steelhead Survival?

Identification of Management Actions

This estuary recovery module identifies 23 management actions to improve the survival of salmon and steelhead migrating through and rearing in the estuary and plume environments. Table ES-1 identifies these management actions and shows their relationship to threats to salmonid survival.

TABLE ES-1
Management Actions to Address Threats

	Threat	Management Action
Flow-related threats	Climate cycles and global warming[2]	**CRE[1]-1:** Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.[2]
		CRE-2: Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.[2]
		CRE-3: Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.[2]
	Water withdrawal	***CRE-3:*** *Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.*
	Flow regulation	**CRE-4**: Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to provide better transport of sediments and access to habitats in the estuary, plume, and littoral cell.
Sediment-related threats	Entrapment of sediment in reservoirs	**CRE-5:** Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.
	Impaired sediment transport	**CRE-6:** Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.
		CRE-4: *Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to provide better transport of sediments and access to habitats in the estuary, plume, and littoral cell.*
	Dredging	**CRE-7:** Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.

Structural threats	Pile dikes and navigational structures	**CRE-8:** Remove pile dikes that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.
	Dikes and filling	**CRE-9:** Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.
		CRE-10: Breach or lower dikes and levees to improve access to off-channel habitats.
	Reservoir heating	***CRE-2:*** *Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.*
	Over-water structures	**CRE-11:** Reduce the square footage of over-water structures in the estuary.
Food web-related threats	Reservoir phytoplankton production	***CRE-10:*** *Breach or lower dikes and levees to improve access to off-channel habitats.*
	Altered predator/prey relationships	**CRE-13:** Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.
		CRE-14: Identify and implement actions to reduce salmonid predation by pinnipeds.
		CRE-15: Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.
		CRE-16: Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.
		CRE-17: Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.
		CRE-18: Reduce the abundance of shad entering the estuary.
	Ship ballast practices	**CRE-19:** Prevent new invertebrate introductions and reduce the effects of existing infestations.
Water quality-related threats	Agricultural practices	**CRE-20:** Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.
	Urban and industrial practices	**CRE-21:** Identify and reduce industrial, commercial, and public sources of pollutants.
		CRE-22: Monitor the estuary for contaminants and/or restore contaminated sites.
		CRE-23: Implement stormwater best management practices in cities and towns.
		CRE-1: *Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.*
Other threats	Riparian practices	***CRE-1:*** *Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.*
	Ship wakes	**CRE-12:** Reduce the effects of vessel wake stranding in the estuary.

[1] CRE = Columbia River estuary.

[2] It is unclear what the regional effects of climate cycles and global warming will be during the coming decades. In the absence of unambiguous data on the future effects of climate cycles and global warming in the Pacific Northwest, this recovery plan module takes a conservative approach of assuming reduced snowpacks, groundwater recharge, and stream flows, with associated rises in stream temperature and demand for water supplies. The climate-related management actions in Table ES-1 reflect this assumption.

Evaluating Management Actions: Relationship of Implementation Constraints to Cost and Survival Improvements

Identifying management actions that could reduce threats to salmon and steelhead as they rear in or migrate through the estuary is an important step toward improving conditions for salmonids during a critical stage in their life cycles. However, actual implementation of management actions is constrained by a variety of factors, such as technical, economic, public health and safety, and property rights considerations. In fact, in some cases it will be impossible to realize an action's full potential because its implementation is constrained by past societal decisions that are functionally irreversible. Reclaiming off-channel habitats in the lower Cowlitz River floodplain, for example, is constrained by the development of the city of Longview decades ago. An important assumption of the estuary recovery plan module is that the implementation of each of the 23 management actions identified in the module is highly constrained.

The module makes another important assumption about implementation: Although implementation of actions is constrained, even partial implementation can make important contributions to the survival of salmonids in the estuary, plume, and nearshore.

It is within the context of these two fundamental assumptions that recovery actions are evaluated in the module, in terms of their costs and potential benefits. The evaluation of survival benefits and costs is highly uncertain because it relies on estimates not only of what is technically feasible, but also of what is socially and politically practical. To help characterize survival improvements, the estuary recovery module uses a planning exercise that involves distributing a plausible survival target across the actions to hypothesize a potential amount of improvement that would result from each action. Costs then are developed by identifying projects for each action and units and per-unit costs for each project. Both the survival improvements and costs reflect assumptions about the constraints to implementation and the degree to which those constraints can be reduced given the technical, social, and political context in the Columbia River basin.

Evaluation Results

The estuary recovery plan module estimates that the cost of partial (constrained) implementation of all 23 actions over a 25-year time period is about $500 million. The $500 million estimate in this estuary recovery plan module represents an order-of-magnitude increase over the current level of investment in the estuary and reflects a significant level of effort needed to improve ecosystem health in the estuary, plume, and nearshore over the next 25 years.

Table ES-2 shows the most important management actions for ocean- and stream-type salmonids that emerged from the analysis and planning exercises in the estuary recovery plan module. Many of these actions are the same for ocean and stream types.

TABLE ES-2
Management Actions Important for Survival of Ocean- and Stream-type Salmonids

For Ocean Types	For Stream Types
CRE-01: Protect/restore riparian areas.	CRE-01: Protect/restore riparian areas.
CRE-02: Mitigate/reduce reservoir heating.	CRE-02: Mitigate/reduce reservoir heating.
CRE-04: Adjust the timing, magnitude, and frequency of flows.	CRE-04: Adjust the timing, magnitude, and frequency of flows
CRE-08: Remove pile dikes.	CRE-08: Remove pile dikes.
CRE-09: Protect remaining high-quality off-channel habitat.	CRE-09: Protect remaining high-quality off-channel habitat.
CRE-10: Breach or lower dikes and levees.	CRE-10: Breach or lower dikes and levees.
CRE-21: Identify and reduce sources of pollutants.	CRE-21: Identify and reduce sources of pollutants.
CRE-22: Monitor and restore contaminated sites.	CRE-22: Monitor and restore contaminated sites.
CRE-12: Reduce vessel wake stranding.	***CRE-14: Reduce predation by pinnipeds.***
	CRE-16: Redistribute Caspian terns.
	CRE-17: Redistribute cormorants.

Note: Bold-face italics indicate management actions that would benefit primarily ocean- or stream-type salmonids, rather than both types.

Implementing the suite of actions for ocean-type salmonids would cost approximately $350 million and be expected to achieve approximately 88 percent of the survival target (see Chapter 5 for a description of survival targets) for ocean-type juveniles. Implementing the suite of actions for stream-type salmonids would cost approximately $362 million and be expected to achieve 94 percent of the survival target. Additionally, a gain of 5,000 adult stream types (spring chinook and winter steelhead) is associated with the implementation of CRE-14, "Reduce predation by pinnipeds." Implementation of both suites of actions would cost approximately $367 million, which is less than the sum of the cost for both suites because some actions are common to both lists.

Other Implementation Considerations: Life History Diversity, Cost-Effectiveness, and Achieving Maximum Benefit

It is tempting to pick and choose among the management actions, looking for the path of least resistance to achieve the desired survival improvements. For example, using the results of the Chapter 7 survival improvement planning exercise, it appears obvious that significant improvements in the survival of stream-type salmonids can be achieved by reducing threats associated with predators such as terns, cormorants, pikeminnow, and pinnipeds. However, addressing these threats would improve survival primarily for the dominant life-history strategy displayed by stream-type salmonids; in terms of recovery of ESUs, less dominant stream-type life history strategies also must be addressed. This points to the need to implement additional management actions in the estuary not directly related to predation.

For ocean-type juveniles, management actions that improve the health of the estuarine ecosystem appear to be the linchpin. Ocean-type juveniles reside in the estuary longer than stream types do and, as a result, rely more heavily on a healthy ecosystem to provide them with food and habitat. Given the challenges of making wide-scale ecosystem change, significant improvements for ocean-type juveniles may depend largely on three of the most constrained actions: adjusting flows (CRE-4), breaching or lowering dikes and levees to increase access to off-channel habitats (CRE-10), and restoring contaminated sites (CRE-22). Although these are some of the most expensive actions, their effects could be far-reaching enough that their potential benefits would be at least commensurate with their high costs.

Finally, because the estuary recovery module (by design) takes an optimistic view about what is possible in terms of implementing management actions, in actuality actions probably will not be implemented with the level of effort needed to elicit the desired response. In fact, the most important take-home message of the estuary plan module is that recovery of listed ESUs in the Columbia River may not be possible without properly functioning estuary, plume, and nearshore ecosystems; to achieve a meaningful boost in survival from these ecosystems, every ounce of an action's potential benefit should be explored, and serious consideration should be given to implementing all of the 23 management actions to the fullest extent possible.

CHAPTER 1

The Columbia River Estuary and Plume

Purpose of the Estuary Recovery Plan Module

The purpose of this estuary recovery plan module is to identify and prioritize management actions that, if implemented, would reduce threats to salmon and steelhead in the Columbia River estuary and plume. This was accomplished by reviewing and synthesizing current literature and gaining input and guidance from area experts, including staff at NOAA/NMFS's Northwest Fisheries Science Center.

The estuary recovery plan module identifies and prioritizes salmon and steelhead limiting factors (see Chapter 3) and links them to the underlying environmental and human threats that have contributed to declines in abundance in the estuary (see Chapter 4). Threats are prioritized based on the priority of the limiting factors they contribute to and their relative contribution to those limiting factors. Management actions that have potential to reduce threats are identified in Chapter 5 and evaluated in terms of their implementation constraints, potential benefits, and costs. In Chapter 7, these factors are integrated to help characterize a scenario for improving the survival of salmonids as they rear in and migrate through the estuary, plume, and nearshore.

This estuary recovery plan module has important relationships to other planning processes and documents. In the context of Columbia River basin recovery planning, the estuary module provides information on how conditions in the estuary and plume affect the 13 upstream evolutionarily significant units (ESUs). Over the next several years, NOAA Fisheries will meld the management actions identified in the various recovery plans for Columbia River basin salmon and steelhead to develop a prioritized set of actions that will most effectively restore listed salmonids to healthy status. This estuary recovery plan module was developed in part using the Northwest Power and Conservation Council's "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" (in *Columbia River Basin Fish and Wildlife Program*, Northwest Power and Conservation Council 2004) and is consistent with its management actions. In addition, the estuary recovery plan module has a direct relationship to the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) remand collaborative process in the lower Columbia River. In general, the estuary habitat section of the BiOp uses information found in the estuary recovery plan module as its basis.

The process of identifying and prioritizing management actions in the estuary module has inherent difficulties. Although scientific knowledge about the estuary is advancing, it is still incomplete. In addition, effective management solutions must acknowledge irreversible changes in estuary conditions over time, reflect the social and political will of the region, and focus on the biological and physical needs of the fish. In the final analysis, it is likely that science will never fully explain how every action affects the viability of fish. It will be up to current and future residents of the basin to determine how much they are willing to pay or do without in order to return salmon and steelhead to viable levels.

Estuary Characteristics

The geographic scope of the estuary recovery module encompasses areas from Bonneville Dam (River Mile [RM] 146) to the mouth of the Columbia River, including the Columbia River plume and littoral cell. Tributaries entering the estuary are referred to for context only, as they are treated in other planning efforts, such as the Lower Columbia Fish Recovery Board's *Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan* (2004).

The historical (circa 1880) total surface area of the Columbia River estuary has been estimated at up to 186 square miles (Thomas 1983, Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004). The current estuary surface area is approximately 159 square miles (Northwest Power and Conservation Council 2004). The Willamette River is the largest tributary to the lower Columbia River. Other major tributaries originating in the Cascade Mountains include the Sandy River in Oregon and the Washougal, Lewis, Kalama, and Cowlitz rivers in Washington. Coastal range tributaries include the Elochoman and Grays rivers in Washington and the Lewis and Clark, Youngs, and Clatskanie rivers in Oregon. The general geography of the estuary is shown in Figure 1-1.

Tidal impacts in water levels are observed as far upstream as Bonneville Dam at RM 146. During low flows, reversal of river flow has been measured as far upstream as Oak Point at RM 53. The intrusion of saltwater is generally limited to Harrington Point at RM 23; however, at lower daily flows saltwater intrusion can extend past Pillar Rock at RM 28.

Today, the lowest river flows occur during September and October, when rainfall and snowmelt are lowest (Northwest Power and Conservation Council 2004). The highest flows occur from April to June and result from snowmelt runoff. High flows also occur between November and March and are caused by heavy winter precipitation. Discharge at the mouth of the river currently ranges from 100,000 to 500,000 cubic feet per second (cfs). Historically, unregulated flows were both lower and higher—79,000 and 1 million cfs, respectively (Neal 1972 and Lower Columbia River Estuary Partnership 2002 as cited in Northwest Power and Conservation Council 2004).

Estuary Reaches

For the purposes of this estuary recovery plan module, the estuary is broadly defined to include the entire continuum where tidal forces and river flows interact, regardless of the extent of saltwater intrusion (Fresh et al. 2005, Northwest Power and Conservation Council 2004). For planning purposes, the upstream boundary is Bonneville Dam and the downstream boundary includes the Columbia River plume. These two divisions—the estuary and plume—have been used extensively in this estuary recovery plan module as distinct zones. Further delineation of the estuary has occurred, including efforts by Thomas (1983), Johnson et al. (2003), and—more recently—the Lower Columbia River Estuary Partnership (2005).

FIGURE 1-1
The Columbia River Estuary and Its Major Tributaries
(Reprinted from Bottom et al. 2005.)

In this estuary recovery plan module, limiting factors, threats, and management actions are identified at the finest reach level possible. In some cases, this may be as general as making a distinction between the estuary and plume. In other cases, additional definition is available at the reach scale. The Lower Columbia River Estuary Partnership, in conjunction with the University of Washington and U.S. Geological Survey, is developing several estuary landscape classifications. Of these overlaying classifications, the estuary recovery module uses the Level 3 Stratum, which organizes the estuary between the mouth and Bonneville Dam into eight lettered reaches (Lower Columbia River Estuary Partnership 2005).

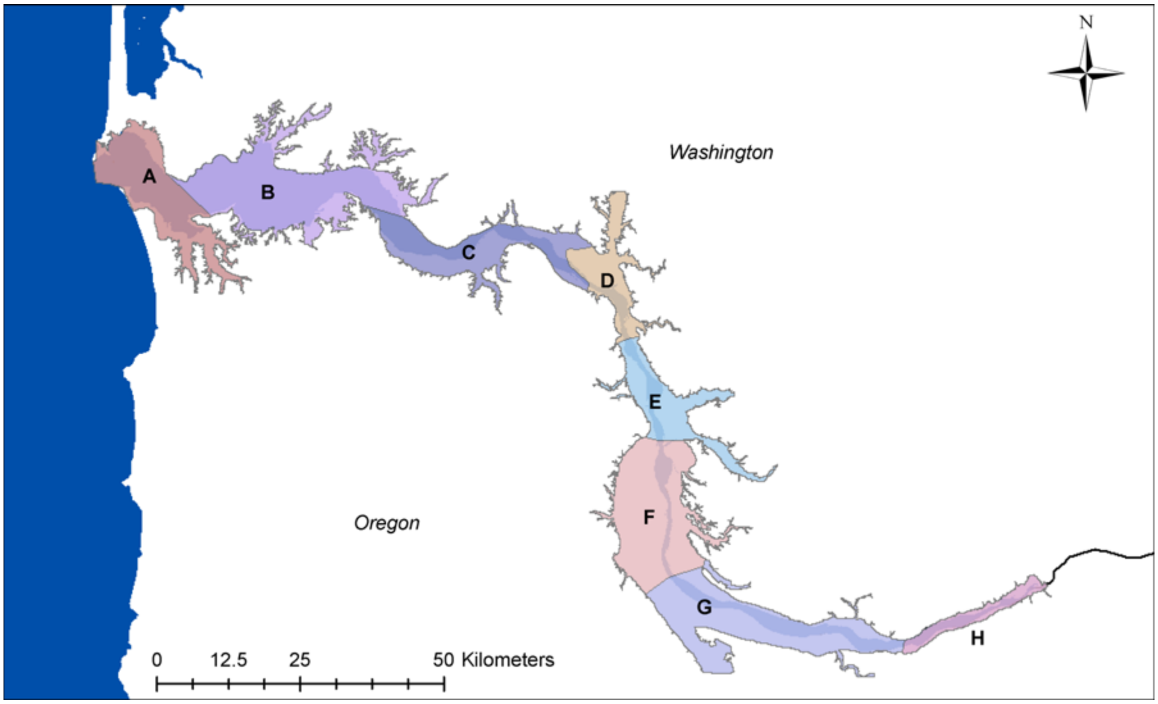

FIGURE 1-2
Lower Columbia River Estuary Reaches
(Reprinted from Northwest Power and Conservation Council 2004.)

Figure 1-2 shows these eight reaches, which can be described briefly as follows:

- **Reach A**. This area includes the estuary entrance (Clatsop Spit and Trestle Bay), Bakers Bay, and Youngs Bay. The entrance is dominated by subtidal habitat and has the highest salinity in the estuary. Historically, the estuary entrance was a high-energy area of natural fluvial land forms with a complex of channels, shallow water, and sand bars. Reach A supports the Columbia River plume, which creates a unique low-salinity, high-productivity environment that extends well into the ocean. The dynamic nature of the entrance area has changed as a result of dredging and the construction of jetties. These activities have limited wave action and the marine supply of sediment.

  Historically, ocean currents and wave action made Bakers Bay a high-energy area, but both currents and wave action have been altered by dredging and jetty construction. The migration of mid-channel islands toward the interior of Baker Bay also has sheltered the area from wave action. As a result, tidal marsh habitat has recently started to develop in some areas, although much of the historical tidal marsh and tidal swamp habitat has been lost because of dike construction in the floodplain. Given its proximity to the river mouth, Baker Bay consists primarily of brackish water.

  Youngs Bay is characterized by a broad floodplain and historically was abundant in tidal marsh and swamp habitat. Diking and flood control structures have been used to convert floodplain habitat in the area to pasture. The remaining fragmented tidal marsh and tidal swamp habitats in Youngs Bay are thought to be different in structure and vegetative community than historical conditions of these habitats.

- **Reach B**. This area includes what has been referred to as the mixing zone (Northwest Power and Conservation Council 2004), Grays Bay, and Cathlamet Bay. The mixing zone is an area characterized by a network of mid-channel shoals and flats, such as Desdemona and Taylor Sands. It also has the highest variation in salinity within the estuary because of the interactions between tide cycles and river flows. The estuarine turbidity maximum (see p. 3-8), which is created through these interactions, is often located within this area of Reach B.

  Grays Bay is found on the Washington side of the river in Reach B. Historically, water circulation in this area was a result of interactions between river flow and tidal intrusion. Pile dike fields constructed adjacent to the main Columbia River navigation channel have decreased circulation in Grays Bay. This circulation change is suspected of causing flooding problems in the Grays and Deep River valley bottoms and may have promoted the beneficial development of tidal marsh habitat in the accreting bay. Dike construction, primarily for pasture conversion, has isolated the main channel from its historical floodplain and eliminated much of the historical tidal swamp habitat.

  Cathlamet Bay is located on the Oregon side of the river in Reach B. This area is characterized by some of the most intact and productive tidal marsh and swamp habitat remaining in the estuary, and a large portion of Cathlamet Bay is protected by the Lewis and Clark National Wildlife Refuge. The western edge of Cathlamet Bay contains part of the brackish oligohaline zone, which is thought to be important during the transition of juvenile anadromous fish from freshwater to saltwater. Portions of Cathlamet Bay have lost substantial acreage of tidal swamp habitat as a result of dike construction. Conversely, tidal marsh habitat has formed along the fringe of dredge disposal locations.

- **Reach C**. This area, which includes deep channels and steep shorelines on both sides of the river, ends just downstream of the city of Longview. The narrow channel structure produces an area dominated more by tidal swamp habitat than by edge habitat (tidal marsh). Reach C is typically dominated by freshwater, except during low river flow or large flood tides. Dike construction and clearing of vegetation have resulted in a substantial loss of tidal marsh habitat on Puget Island and within the Skamokawa and Elochoman floodplains. Wallace Island and Crims Island also are located within Reach C.

- **Reach D**. This area begins just downstream of Longview and ends near the city of Kalama. Reach D is distinct from the downstream reaches in its geology, vegetation, and climate. It includes flows from the Cowlitz and Kalama rivers. Extensive diking and filling around Longview and the mouth of the Kalama River have significantly reduced access to the floodplain, and islands created through the disposal of dredged material are prevalent. High levels of polychlorinated biphenyls (PCBs) have been detected in the Longview and Kalama industrial area.

- **Reach E**. This area includes the river upstream of the city of Kalama to Woodland. The Lewis River system, including the North Fork and East Fork, flows into the Columbia River in Reach E. Sandy, Goat, Deer, Martin, and Burke islands are included in Reach E. Extensive diking has occurred on Deer Island and around the city of Woodland.

- **Reach F**. This area includes the river upstream of the confluence with the Lewis River up to and including Salmon Creek. Islands included in this reach are Bachelor and Sauvie. Sloughs include the Lake River system and Multnomah Channel. Scappoose Bay is relatively undiked; however, Sauvie Island and Bachelor Island have been extensively diked.

- **Reach G**. This area includes the river upstream of its confluence with Salmon Creek and extends upstream of Reed Island. This reach is dominated by flows from the Willamette, Washougal, and Sandy rivers. The cities of Portland and Vancouver straddle the Columbia River in this reach. Islands included in this reach are Hayden Island, Government Island, Lady Island, and Reed Island. Extensive diking has reduced the floodplain from the confluence of the Willamette River upstream to the mouth of the Sandy River. High readings of PCBs and polycyclic aromatic hydrocarbons (PAHs) are found along the lower Willamette River and the channelized banks of the Columbia River in this reach. Significant numbers of industrial piers and over-water structures line the Willamette and Columbia rivers in this reach.
- **Reach H**. This area includes the river upstream from Reed Island to Bonneville Dam. This reach receives flow from many small tributaries, including Gibbons, Duncan, Hamilton, Hardy, and Multnomah creeks. Notable islands in this reach include Ackerman and Skamania islands. Reach H includes the entrance to the Columbia River Gorge, which is characterized by steep slopes. Little diking has occurred in this area, primarily because of the lack of floodplain.

The Lower Columbia River Estuary Partnership, in conjunction with Pacific Northwest National Laboratory, has further delineated the estuary into discrete management areas at approximately the 6th field hydrologic unit code (HUC). These management areas are geospatially referenced to a variety of data sets that can be used to generate statistics and geographic information system (GIS) maps. Statistics relating to floodplain changes, diking coverage, tide gates, contaminants, structures, and dredge fill locations are included where appropriate. GIS maps showing some of these features are presented in Appendix A. For additional information, see the *Columbia River Estuary Habitat Monitoring Plan* (Lower Columbia River Estuary Partnership 2004b).

Columbia River Plume

The Columbia River plume is generally defined by a reduced-salinity contour near the ocean surface of approximately 31 parts per thousand (Fresh et al. 2005). In high flows, the plume front is easily recognized by the sharp contrast between the sediment-laden river water and the clearer ocean (see Figure 1-3). The plume’s location varies seasonally with discharge, prevailing near-shore winds, and ocean currents. In summer, the plume extends far to the south and offshore along the Oregon coast. During the winter, it shifts northward and inshore along the Washington coast. Strong density gradients between ocean and plume waters create stable habitat features where organic matter and organisms are concentrated (Fresh et al. 2005). The Columbia River plume can extend beyond Cape Mendocino, California, and influences salinity in marine waters as far away as San Francisco (Northwest Power and Conservation Council 2000). For the purposes of this estuary recovery plan module, the plume is considered to be off the immediate coasts of both Oregon and Washington and to extend outward to the continental shelf.

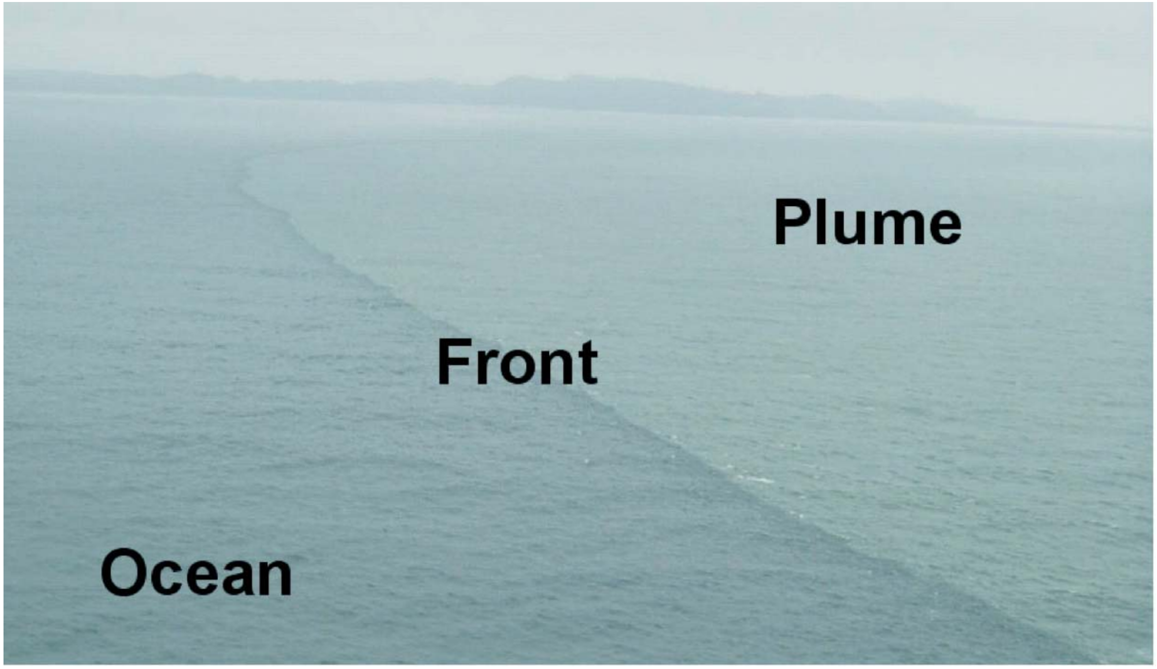

FIGURE 1-3
Plume Front
(Photo courtesy of NOAA Fisheries.)

Major Land Uses

A variety of land uses are found adjacent to the Columbia River estuary. The area contains multiple cities and political jurisdictions, including Portland, which is Oregon's largest city, and Vancouver, the fourth largest Washington city. Smaller cities include Astoria, Cathlamet, Longview, Kalama, Woodland, and Camas. Approximately 2.5 million people live in the vicinity of the estuary, and more are coming. Five deep-water ports in the area support a shipping industry that transports 30 million tons of goods annually (Lower Columbia Fish Recovery Board 2004), worth $13 billion each year (Columbia River Channel Improvement Reconsultation Project). Timber harvest occurs throughout the basin—six major pulp mills contribute to the region's economy. Until recently, aluminum plants along the river produced 43 percent of the country's aluminum. Agriculture is widespread throughout the floodplain and includes fruit and vegetable crops along with beef and dairy cattle. Commercial and recreational fishing activity plays an important role in local economies, bringing in millions of dollars of revenue each year. Primary outdoor recreational activities include fishing, wildlife observation, hunting, boating, hiking, and windsurfing.

Two Centuries of Change

Before Euro-American settlement of the Pacific Northwest, the Columbia River estuary and plume served as a physical and biological engine for salmon. Juveniles from hundreds of populations of steelhead, chum, chinook, and coho entered the estuary and plume every month of the year, with their timing honed over evolutionary history to make use of habitats rich with food. A beach seine survey during any month of the year would likely have yielded salmon of all species and many populations, with individuals of many sizes.

This genetic variation in behavior was an important trait that allowed salmon and steelhead to occupy many habitat niches in time and space. It also guarded populations against catastrophic events such as volcanic eruptions (Bottom et al. 2005).

Today the Columbia River estuary and plume are much different. Notably, the North and South jetties at the mouth of the river restrict the marine flow of nutrients into the estuary. Dikes and levees lining the Washington and Oregon shores prevent access to areas that once were wetlands. New islands have been formed by dredged materials, and pile dike fields reach across the river, redirecting flows. Less visible but arguably equally important are changes in the size, timing, and magnitude of flows that, 200 years ago, regularly allowed the river to top its banks and provide salmon and steelhead with important access to habitats and food sources. Flow factors, along with ocean tides, are key determinants of habitat opportunity and capacity in the estuary and plume.

Salmon thrived in the Columbia River for 4,000 years. In the last 100 years, the entire Columbia River has undergone tremendous change as a direct result of people living and working in the basin. While the threats to salmon persistence are very diverse, at some level it is the increase in human population in the Northwest that underlies every human threat. There are an estimated 5 million people in the Columbia River basin today, and somewhere between 40 million and 100 million people are predicted to be living in the basin by the end of the twenty-first century (National Research Council 2004). If we want healthy salmon runs at the same time that our population is multiplying, our interactions with land and water must pose fewer threats to salmonids than they have in the last 100 years. Before identifying management actions that could do just that, this document discusses which salmonids currently use the Columbia River basin, and how.

CHAPTER 2

Salmonid Use of the Estuary and Plume

The estuary and plume provide salmonids with a food-rich environment where they can undergo the physiological changes needed to make the transition from freshwater to saltwater habitats, and vice versa. Every salmonid that spawns in the Columbia River basin undergoes such a transformation twice in its lifetime—the first time during its first year of life (or soon after) when migrating out to sea, and the second time 1 to 3 years later, as an adult returning to spawn. The transition zone where juvenile salmonids undergo this transformation is thought to extend from the estuary itself to the near-shore ocean and plume habitats and into rich upwelling areas near the continental shelf (Casillas 1999).

The estuary and plume also serve as rich feeding grounds where juveniles have the opportunity for significant growth as they make the important transition from freshwater to seawater. Studies have shown that juvenile salmon released within the estuary and plume returned as larger adults and in greater numbers than juveniles released outside the transition zone (Casillas 1999). Thus, although juvenile salmonids face risks from a variety of threats in the estuary and plume (see Chapter 4), these environments can be highly beneficial. In the salmon life cycle, successful estuarine and plume residency by juveniles is critical for fast growth and the transition to a saltwater environment.

Clearly, the Columbia River estuary and plume are uniquely important to salmonids, and conditions in the estuary and plume undoubtedly affect salmonid survival. Yet the estuary and plume represent just one in a series of ecosystems that salmon use in their complex life cycle. Exploring the connections among these ecosystems, the habitats they provide, the salmonid species that use them, and the variety of life histories those salmonids display sheds further light on the role of the estuary and plume in the salmonid life cycle.

Salmonid Species in the Columbia River Basin

Before Euro-American settlement, the Columbia River basin was used extensively by six species of the family Salmonidae and the genus *Oncorhynchus*: chinook, chum, coho, and sockeye salmon plus two trout species: steelhead and sea-run cutthroat (Lichatowich 1999). Within these six species, 13 ESUs,[1] representing more than 150 populations of salmon and steelhead, have been listed as threatened or endangered under the federal Endangered Species Act (Bottom et al. 2005). All 13 of the ESUs use the estuary and plume as an essential link in their far-reaching life cycles.

It is estimated that historically up to 16 million salmon from perhaps hundreds of distinct populations returned to the Columbia River each year (Lichatowich 1999). This contrasts markedly with recent returns of salmon and steelhead adults, which number approximately

[1] NOAA Fisheries has revised its species determinations for West Coast steelhead under the Endangered Species Act (ESA), delineating steelhead-only “distinct population segments” (DPSs). The former steelhead ESUs included both anadromous steelhead trout and resident, non-anadromous rainbow trout, but NOAA Fisheries listed only the anadromous steelhead. The steelhead DPS does not include rainbow trout, which are under the jurisdiction of the U.S. Fish and Wildlife Service. In January 2006, NOAA Fisheries listed five Columbia River basin steelhead DPSs as threatened (71 FR 834). To avoid confusion, references to ESUs in this estuary recovery plan module imply the steelhead DPSs as well.

1.7 million. To achieve these returns, an estimated 200 million juveniles are produced each year, approximately 50 to 95 percent of which are of hatchery origin, depending on the species (Bottom et al. 2005 as cited in Columbia Basin Fish and Wildlife Authority 1990 and Genovese and Emmett 1997).

Life History Types and Strategies

In discussing salmonids, fish scientists commonly refer to ocean type and stream type to distinguish two main freshwater rearing strategies. Ocean-type salmonids are characterized by migration to sea early in their first year of life, after spending only a short period rearing in freshwater (Fresh et al. 2005). Conversely, stream-type salmonids are characterized by migration to sea after rearing for more extended periods in freshwater, usually at least 1 year (Fresh et al. 2005). Table 2-1 shows the general characteristics of ocean-type and stream-type ESUs.

TABLE 2-1
Characteristics of Ocean- and Stream-Type Salmonids

Attribute	Ocean-Type Fish: fall chinook, chum	Stream-Type Fish: coho, spring chinook, steelhead
Residency time	Short freshwater residence Longer estuarine residence Longer ocean residence	Long freshwater residence (>1 year) Shorter estuarine residence Shorter ocean residence
Size at estuary entry	Smaller	Larger
Primary habitat use	Shallow-water estuarine habitats, especially vegetated ones	Deeper, main-channel estuarine habitats; use plume more extensively

Adapted from Fresh et al. 2005.

In the Columbia River estuary, both ocean- and stream-type salmonids experience significant mortality. However, because the two types typically spend different amounts of time in the estuary and plume environments and use different habitats, they are subject to somewhat different combinations of threats and opportunities.

For ocean-type juveniles, mortality is believed to be related most closely to lack of habitat, changes in food availability, and the presence of contaminants. Stream types are affected by these same factors, although presumably to a lesser degree because of their shorter residency times in the estuary. However, stream types are particularly vulnerable to bird predation in the estuary because they tend to use the deeper, less turbid channel areas located near habitat preferred by piscivorous birds (Fresh et al. 2005), and they are subject to pinniped predation when they return to the estuary as adults. Also, stream-type salmonids are thought to use the low-salinity gradients of the plume to achieve growth and gradually acclimate to saltwater. Changes in flow and sediment delivery in the plume may affect stream-type juveniles in a way similar to how estuary conditions affect ocean-type juveniles; however, additional research is needed to determine more precisely how stream types use the plume (Casillas 2006).

Fish scientists also describe salmonids in terms of the life history strategies they employ, meaning a population’s unique pattern of preferred spawning substrate, habitat use, migration timing, length of estuarine and marine residency, and so on. For thousands of years, Columbia River salmonids exhibited great diversity in life history strategies, exploiting every habitat niche available to them. This rich diversity in life history strategies allowed salmonids to persist as species for millennia even when individual populations were wiped out by disease or natural disturbances such as volcanic eruptions.

Table 2-2 identifies the six basic life history strategies used by salmon and steelhead in the Columbia River and their general attributes.

TABLE 2-2
Life History Strategies and Their Attributes

Life History Strategy	Attributes
Early fry	Freshwater rearing: 0 - 60 days Size at estuarine entry: <50 mm Time of estuarine entry: March - April Estuarine residence time: 0 - 40 days
Late fry	Freshwater rearing: 20 - 60 days Size at estuarine entry: <60 mm Time of estuarine entry: May - June, present through Sept. Estuarine residence time: <50 days
Early fingerling	Freshwater rearing: 60 - 120 days Size at estuarine entry: 60 - 100 mm Time of estuarine entry: April - May Estuarine residence time: <50 days
Late fingerling	Freshwater rearing: 50 - 180 days Size at estuarine entry: 60 - 130 mm Time of estuarine entry: June - October, present through winter Estuarine residence time: 0 - 80 days
Subyearling (smolt)	Freshwater rearing: 20 - 180 days Size at estuarine entry: 70 - 130 mm Time of estuarine entry: April - October Estuarine residence time: <20 days
Yearling	Freshwater rearing: >1 year Size at estuarine entry: >100 mm Time of estuarine entry: February - May Estuarine residence time: <20 days

Adapted from Fresh et al. 2005.

Changes in Life History Diversity

The 13 ESUs in the Columbia River express much less diversity in life history strategies now than they did historically. Formerly, both ocean- and stream-type salmonids entered the estuary and plume throughout the year, at a great variety of sizes, which reflected the various life history strategies in Table 2-2. Today juveniles tend to arrive in pulses and are more uniform in size.

TABLE 2-3
Linkage between Salmonid ESU, Dominant Life History Type, and Life History Strategy

ESU	Life History Type	Historical and Current Life History Strategies					
		Early Fry	Late Fry	Early Fingerling	Late Fingerling	Sub-yearling	Yearling
Columbia River chum salmon	Ocean	Abundant	Abundant	Absent	Absent	Absent	Absent
Snake River sockeye salmon	Stream	Absent	Absent	Absent	Absent	Rare	Abundant
Lower Columbia River coho salmon	Stream	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Upper Columbia River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Snake River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Lower Columbia River steelhead	Stream	Absent	Absent	Absent	Historically rare, currently absent	Historically medium, currently rare	Abundant
Middle Columbia River steelhead	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Abundant
Upper Willamette River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Snake River fall chinook salmon	Ocean	Absent	Absent	Historically medium, currently rare	Historically medium, currently rare	Abundant	Historically rare, currently medium
Upper Willamette River chinook salmon	Ocean	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Historically medium, currently rare	Historically rare, currently medium	Abundant
Lower Columbia River fall chinook salmon	Ocean	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently rare	Historically medium, currently abundant	Rare
Upper Columbia River spring chinook salmon	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Snake River spring/summer chinook salmon	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant

Adapted from Fresh et al. 2005.

Table 2-3 shows losses in life history diversity in the Columbia River. The table identifies the dominant life history type (ocean vs. stream) and strategies for each ESU, the prevalence of each life history strategy, and whether that prevalence has changed from historical times to the present. The number of life history strategies employed by some ESUs, such as Columbia River chum, have not changed. But for other ESUs—notably the Lower Columbia River coho—several life history strategies that used to exist have been lost.

Losses in life history diversity can also be seen in Figure 2-1, which compares historical and current estuarine life history types for one brood year of chinook salmon. The figure shows a reduction in the number of strategies available in the contemporary versus historical estimates.

Some of the losses in salmonid life history diversity are attributable to habitat alterations throughout the Columbia River basin that have eliminated entire populations of salmon and steelhead. In other cases, hatcheries and harvest impacts have reduced the health and genetic makeup of species. As a result, many of the populations currently using the estuary and plume are significantly different than the fish that historically used the various habitats available to them, and some existing habitats may not be being used by salmonids at all.

Relationship of the Estuary to the Columbia River Basin

In 2005 scientists working at NOAA/NMFS's Northwest Fisheries Science Center published a technical memorandum that establishes an ecologically based conceptual framework for understanding the estuary within the larger context of the Columbia River basin. In *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*, Bottom et al. (2005) hypothesize that Columbia River salmon's resilience to natural environmental variability is embodied in population and life history diversity, which maximizes the ability of populations to exploit available estuarine rearing habitats. The conceptual framework is based on Sinclair's (1988) member/vagrant theory, which proposes general principles for understanding marine species with complex life cycles.

Bottom et al. (2005) hypothesize that how an individual salmon or steelhead uses the ecosystems it encounters—when juveniles migrate, how big they are, what habitats they use, and how long they stay in a particular habitat—correlates directly to the discrete population of fish that individual is part of. In other words, different populations within ESUs employ different life history strategies. For example, two populations of steelhead within an ESU may produce juveniles of different sizes that enter the estuary at different times, and these juveniles may use distinct habitats that may be available only at that particular time.

Considering that the estuary is just one of three major ecosystems used by salmon and steelhead, the member/vagrant theory implies that how juveniles migrate and use estuarine habitat may depend as much on the status of upriver habitats and corresponding populations as on environmental conditions in the estuary itself (Bottom et al. 2005). In other words, if there is a close relationship between particular geographical features in the estuary and the life history of a discrete salmonid population, use of the estuary may reflect the abundance and life history strategy of the associated population, which is in part a function of upstream conditions. Thus, if salmonid migration and rearing behaviors in the estuary are linked to specific geographic features and those features are reduced or eliminated, mortality in the population that uses those features increases (Bottom et al.

2005). By the same token, if salmonid populations are lost because of other factors (such as blockage by dams), habitats in the estuary may be left unoccupied.

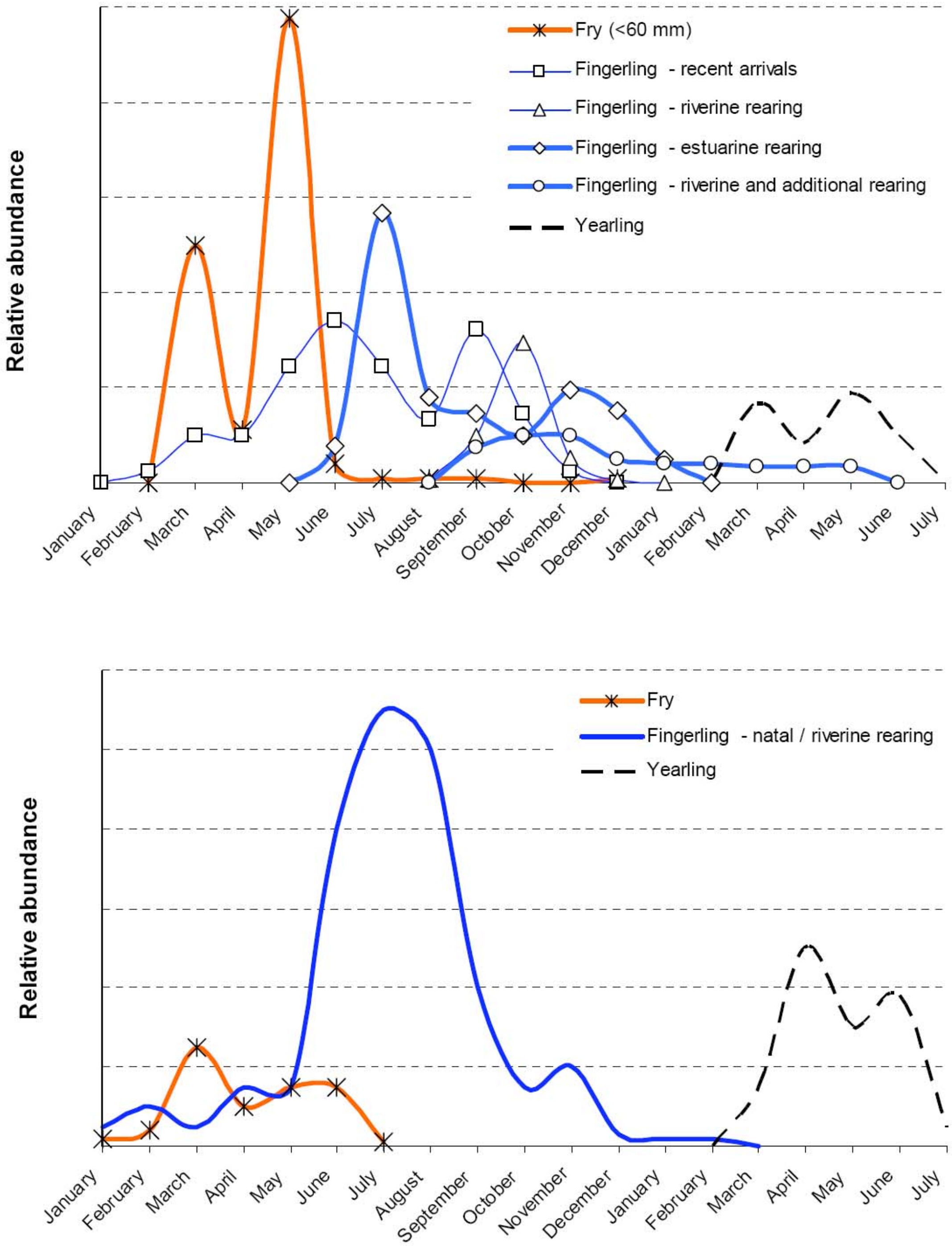

FIGURE 2-1
Historical and Contemporary Early Life History Types of Chinook Salmon in the Columbia River Estuary
(Reprinted from Fresh et al. 2005.)

The implication for salmon recovery in the Columbia River basin is that habitat use by salmonids must be considered from a multi-ecosystem perspective if we are to understand which components of each ecosystem—tributaries, mainstem, estuary, plume, nearshore, and ocean—are limiting the overall performance of salmon.

Summary

Since 1991, 13 Columbia River ESUs have been listed as threatened or endangered under the federal Endangered Species Act. During their complex life cycles, listed salmon and steelhead rely on many diverse ecosystems, from tributaries to ocean environments, that span hundreds or thousands of miles. For recovery efforts to be successful, it is necessary to understand salmonids’ requirements during all stages of their life cycles. Thus, although the estuary and plume represent important stages in the salmonid life cycle, these ecosystems must be considered within the context of other life cycle stages if management actions are to be effective. Perhaps most central to the recovery of listed ESUs is the importance of conserving biological diversity and the native ecosystems it depends on (Bottom et al. 2005).

CHAPTER 3

Limiting Factors

Chapter 3 identifies and prioritizes the key physical, chemical, or biological features impeding ESUs and their component populations from reaching viability status. These features are referred to as limiting factors. The discussion of limiting factors in this chapter pertains to the estuary and plume; however, upstream limiting factors in some cases have a direct bearing on conditions in the estuary.

Determining Estuary Habitat Limiting Factors

Sources

For this estuary recovery module, limiting factors were identified and prioritized based on a thorough review and synthesis of pertinent literature, supplemented by input from area experts that included staff from NOAA/NMFS's Northwest Fisheries Science Center and NOAA/NMFS – Northwest Regional Office, the Lower Columbia River Estuary Partnership, and the Lower Columbia Fish Recovery Board. Several key documents provided consistent guidance. They included the following:

- *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon* (Bottom et al. 2005)—NOAA technical memorandum
- *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability* (Fresh et al. 2005)—NOAA technical memorandum
- "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" and its supplement—Northwest Power and Conservation Council (2004)

These three literature sources, and others, identified and prioritized limiting factors in a similar manner. But it should be noted that the three sources have separate goals, and this affects each document's structure and content. Thus, the depth and breadth of information were not always consistent across documents.

Mortality Estimates

Estimates of salmon and steelhead mortality in the estuary and mainstem are not well supported in the literature; however, some modeling efforts have made assumptions about estuary mortality. One example is Ecosystem Diagnosis and Treatment (EDT), a life-cycle model that accounts for the estuarine stage of salmon and steelhead in tributaries of the Columbia River. For lower Columbia River ESUs, EDT assumes 18 to 58 percent mortality for various populations.

In addition, new research is currently under way by NOAA Fisheries, the U.S. Army Corps of Engineers, and Battelle Laboratories to estimate the survival rate of juvenile salmonids in the lower Columbia River. This research involves new technologies for miniaturizing acoustic tags to a size capable of tracking yearling and subyearling juveniles. Current technology developed for the project allows for the tracking of subyearlings of sizes down to approximately 90 mm. Results for the first year (2005) have not been formally released; however, preliminary data indicate an approximate range of survival of 65 to 75 percent for subyearlings and yearlings during their residency in the estuary (Ferguson 2006a). It is probable that actual survival rates are lower than these preliminary estimates suggest because the research did not address mortality among juveniles smaller than 90 mm or mortality occurring in the plume and nearshore.

There are reliable mortality estimates for a few limiting factors. For example, Caspian tern predation is estimated to be responsible for the mortality of about 3.6 to 5.9 million smolts each year (2006 and 1998 data, respectively; from Bonneville Power Administration, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers 2004 and Roby 2006). If these estimates are accurate, tern predation may be responsible for the mortality of up to 6 percent of the outmigrating stream-type juveniles in the Columbia River basin. Good estimates also exist for mortalities caused by double-crested cormorants; these estimates are similar to those for terns.

Other limiting factors, such as pinnipeds, ship wake stranding, and toxic contaminants, have incomplete mortality estimates associated with them. In most other cases it is very difficult to point to a specific limiting factor and then estimate mortality. This is because of the inherent complexity associated with connecting the physical, chemical, and biological features that limit the productivity of salmon and steelhead.

Density Dependence

One potential limiting factor that is not included in this chapter's identification and prioritization of limiting factors is density dependence, which refers to competition among hatchery and naturally produced fish. There is growing awareness among scientists studying the Columbia River estuary that mechanisms related to density dependence may limit salmon and steelhead while they are using estuary and plume habitats. The principle is simple: It is possible that too many fish are competing for limited habitat and associated resources in the estuary at key times, and that the resulting stressors translate into reduced salmonid survival. Density dependence can occur at any stage in the salmon and steelhead life cycle and may be exacerbated by the introduction of large numbers of hatchery fish released over a relatively short time period.

Scientists studying Skagit River fall chinook have documented density dependence-related mortality as a result of loss of habitat in the Skagit estuary and believe that such mortality can be attributed to a 75 percent loss of tidal delta estuarine habitat (Beamer et al. 2005). With similar habitat losses in the Columbia River estuary, NOAA/NMFS's Northwest Fisheries Science Center is currently investigating potential density dependence mortality there, and results should be available soon. The *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* raised the specter of density dependence in the estuary and recommended continued research to analyze conditions there (Northwest Power and Conservation Council 2004). Thus, although the occurrence of density dependence-related mortality in the Columbia River estuary has not been proven, given the dramatic changes in habitat opportunity and capacity in the estuary over the last 200 years, the question lingers.

Habitat-Related Limiting Factors

Salmonid populations exhibit diverse strategies that guide them through various habitats and ecosystems in specific sequences and patterns. If those sequences and patterns are interrupted, increased mortality may result. Thus, mismatches between the needs of salmonid populations and the availability of habitats to meet those needs can limit salmonid performance in the estuary and plume. The member/vagrant theory discussed in Chapter 2 underscores the need to consider relationships between ESUs' life history strategies and the quality, quantity, and availability of habitats in the estuary and other ecosystems that are interconnected via the salmon and steelhead's complex life cycle.

The habitats that salmonids occupy during their residency in the estuary and plume are formed through the interaction of ocean forces, land, and river flow (Fresh et al. 2005). Flows entering the estuary govern the general availability of habitats, along with sediment transport, salinity gradients, and turbidity, which are themselves aspects of habitat or habitat formation. Over the last 200 years, the magnitude, timing, and frequency of flows have changed significantly, with corresponding effects on the formation and availability of salmonid habitats. Some habitat has been removed, which has reduced the total acreage of the estuary by approximately 20 percent (Fresh et al. 2005). In other cases, particular habitat types have been transformed into other habitat types, and the resulting mosaic of habitats may not be meeting the needs of salmonids as well as the historical pattern of habitats did. For example, approximately 77 percent of historical tidal swamp has been lost (Northwest Power and Conservation Council 2004), while other shallow-water habitats have increased significantly. The loss of tidal swamps and other forested or vegetated wetlands represents a loss of habitat that ocean-type salmonids use during their estuarine residence. In short, habitat opportunity and capacity have been degraded in the estuary and plume, and alterations in flow have contributed significantly to losses in in-channel, off-channel, and plume habitat.

An important goal of this estuary recovery module is to describe the various habitats and limiting factors that both ocean- and stream-type juvenile salmonids encounter in the Columbia River estuary and plume. However, current scientific understanding of how stream-type juveniles use the various habitats they encounter in the estuary and plume is less robust than what is known about ocean types' habitat use. To fill this important knowledge gap, NOAA/NMFS's Northwest Fisheries Science Center and others are exploring how stream-type juveniles expressing all the different possible life history strategies use individual estuarine habitats. The estuary recovery module will be updated periodically to incorporate this emerging information.

Affected salmonids: Because of their longer estuary residence times and tendency to use shallow-water habitats, ocean-type ESUs are more affected by flow alterations that structure habitat and/or provide access to wetland or floodplain areas than are stream-type ESUs. Stream types have relatively short estuary residence times and use the plume much more extensively than ocean types do. Thus stream-type salmonids are affected by habitat elements such as the shape, behavior, size, and composition of the plume (Fresh et al. 2005).

Reduced In-Channel Habitat Opportunity

In-channel habitat opportunity in the estuary is a function of the size of river flows, the timing of river flows, incoming and outgoing tides, and the amount and patterns of sediment accretion. Together, tidal action, river flow, and sediment movement create a constantly changing mosaic of channel habitats as water levels rise and fall, sands shift, and salinity gradients move in response to tides. To support salmonids, the various habitats in the estuary need to be connected both spatially and in time. With twice-daily tidal changes, areas that may be accessible at one point during the day may be inaccessible 6 hours later because of tidal fluctuations. Changes in both flow and sediment transport have reduced in-channel habitat opportunity.

Limiting Factor: Flow-Related Estuary Habitat Changes. The ability of juvenile salmon to access and benefit from habitat depends greatly on instream flow (Fresh et al. 2005). Changes in the quantity and seasonality of flows in the estuary have a direct bearing on whether key habitats are available to salmonids, when those habitats are available, and whether and how they connect with other key habitats. In addition, juvenile salmonids have physiological or behavioral traits that set the timing for their transformation to saltwater, and changes in flows may interrupt this timing.

Both the quantity and timing of instream flows entering the Columbia River estuary and plume have changed from historical conditions (Fresh et al. 2005). Jay and Naik (2002) reported a 16 percent reduction of annual mean flow over the past 100 years and a 44 percent reduction in spring freshet flows. Jay and Naik also reported a shift in the hydrograph to 14 to 30 days earlier in the year, meaning that spring freshets are occurring earlier in the season. In addition, the interception and use of spring freshets (for irrigation, reservoir storage, etc.) have caused increased flows during other seasons (Fresh et al. 2005). These changes in the Columbia River hydrograph are limiting factors for salmon and steelhead and have affected habitat opportunity and capacity in the estuary and plume.

Limiting Factor: Sediment/Nutrient-Related Estuary Habitat Changes. The transport of sediment is fundamental to habitat-forming processes in the estuary through sediment deposition and erosion (Fresh et al. 2005). Sediment from the estuary and upstream sources also affects the formation of nearshore ocean habitats north and south of the Columbia River entrance.

Since the late nineteenth century, sediment transport from the interior basin to the Columbia River estuary has decreased about 60 percent and total sediment transport has decreased about 70 percent (Jay and Kukulka 2003). This reduction in the amount of sediment transport in the Columbia River has affected habitat-forming processes in the estuary and plume (Bottom et al. 2005) and is presumed to be a limiting factor for salmon and steelhead. Although the consequences of the reduced transport of sediment through the estuary and plume are not fully understood, the magnitude of change is very large compared to historical benchmarks (Fresh et al. 2005).

Sediment also provides important nutrients that support food production in the estuary and plume. Microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically. Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004).

Reduced Off-Channel Habitat Opportunity

Columbia River access to its historical floodplain is an important factor for rearing ocean-type juvenile salmonids. Historically, flows that topped the river's bank provided juvenile salmonids with access to low-velocity areas they used as refugia and for rearing. Overbank flows also contributed key food web inputs to the ecosystem and influenced wood recruitment, predation, and competition in the estuary (Fresh et al. 2005).

Today, mainstem habitat in the Columbia and Willamette rivers has been reduced to a single channel (Northwest Power and Conservation Council 2004), and channelization of the estuary has eliminated access to an estimated 77 percent of historical tidal swamps (Fresh et al. 2005). In fact, over the past 200 years the surface area of the estuary has decreased by approximately 20 percent (Fresh et al. 2005).

The near elimination of overbank flooding is a function of both reductions in flow volume and increases in the bankfull level of the Columbia River, among other factors.

Figure 3-1 shows diked areas from the estuary mouth to Bonneville dam. This map was generated from a GIS database recently developed by the Lower Columbia River Estuary Partnership. The new GIS layers provide state-of-the-art statistics and maps depicting the historical floodplain, diked areas, dredged material disposal sites, over-water structures, contaminant monitoring sites, and other key features in the estuary. Some of these features are shown in GIS-based reach maps presented in Appendix A.

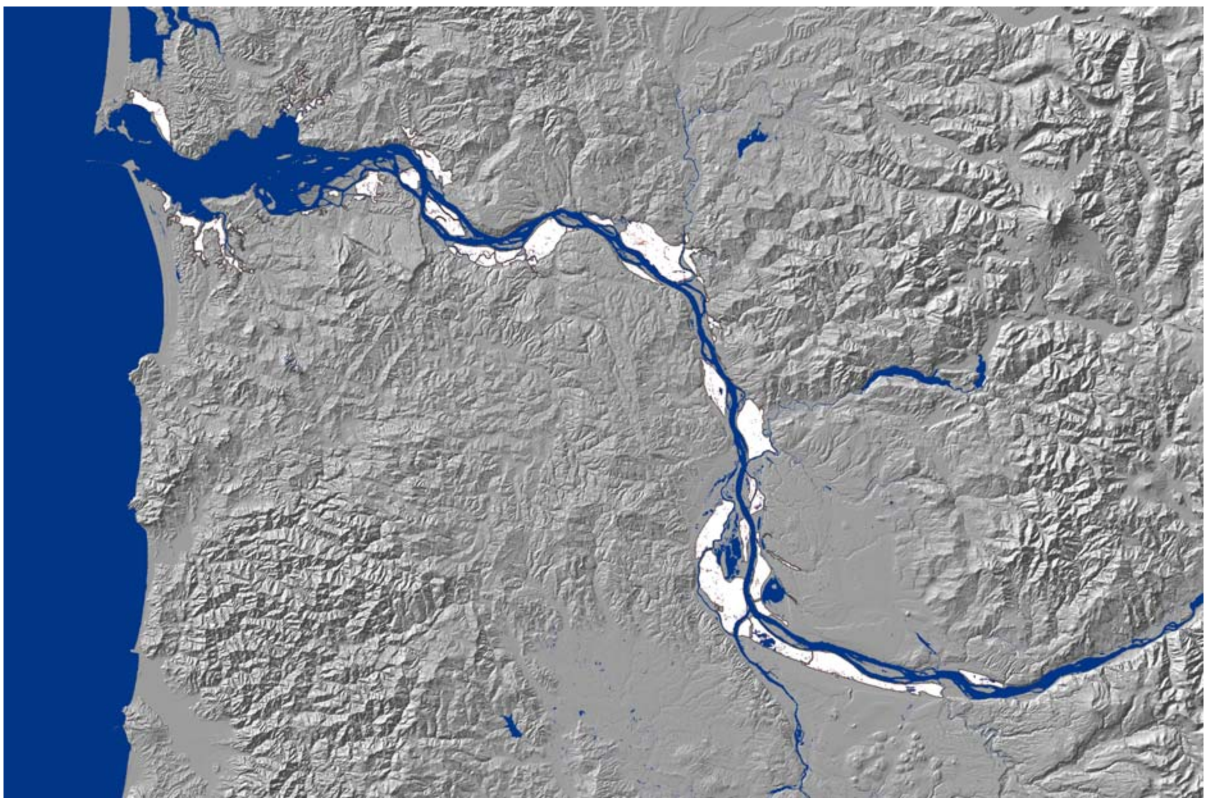

FIGURE 3-1
Diked Areas in the Columbia River Estuary

Limiting Factor: Flow-Related Changes in Access to Off-Channel Habitat. Reduced access to off-channel habitats is a limiting factor for salmon and steelhead because of impacts on food webs and the reduced availability of habitats preferred by fry and fingerlings. Typically, overbank flows were driven by spring freshets, which occurred at the time of year when there was the greatest variety of juvenile salmon and steelhead using the estuary (Fresh et al. 2005). Overbank flows occur much less frequently now than they did historically, in part because climate changes and human alterations have reduced the number of high flows in the Columbia (Jay and Kukulka 2003).

Limiting Factor: Bankfull Elevation Changes. The construction of levees also has reduced the frequency of overbank flows because more river water is needed to cause overbank flow. Historically the bankfull level was 18,000 $m^3 s^{-1}$, while today it is 24,000 $m^3 s^{-1}$—fully one-third more. Only five overbank events have occurred since 1948 (Jay and Kukulka 2003). The reduction in overbank events is a limiting factor because it reduces the availability of food and refugia for ocean-type juveniles rearing in the estuary. Less dominant stream-type juveniles are affected in the same manner.

Reduced Plume Habitat Opportunity

Evidence suggests that the plume supports ocean productivity by increasing primary plant production during the spring freshet period, distributing juvenile salmonids in the coastal environment, concentrating food sources such as zooplankton, and providing refugia from predators in the more turbid, low-salinity plume waters (Fresh et al. 2005). Changes in the Columbia River hydrograph have altered both the size and structure of the plume during the spring and summer months (Northwest Power and Conservation Council 2000).

Limiting Factor: Flow-Related Plume Changes. For juvenile salmonids preparing for ocean life, the plume is believed to function as habitat, as a transitional saltwater area, and as refugia. As mentioned earlier, stream-type ESUs in particular are affected by the size, shape, behavior, and composition of the plume (Fresh et al. 2005).

Over the past 200 years characteristics of the plume have been altered, and conditions caused by reductions in spring freshets and associated sediment transport processes may now be suboptimal for juvenile salmonids (Casillas 1999). Plume attributes affected by changes in flow include surface areas of the plume, the volume of the plume waters, the extent and intensity of frontal features, and the extent and distance offshore of plume waters (Fresh et al. 2005).

Limiting Factor: Sediment/Nutrient-Related Plume Changes. It is believed that the sediment and nutrients transported in the plume fuel ocean productivity and provide relief from predation (Casillas 1999). This is particularly true for stream-type ESUs, who use the plume more extensively than ocean types do and thus are more affected when the amount of plume habitat is reduced.

Limiting Factor: Water Temperature

Water temperatures of between 20° and 24° C are considered the upper range for cold-water species such as salmonids (National Research Council 2004). Alterations in water temperature affect the metabolism, growth rate, and disease resistance of salmonids, as well as the timing of adult migrations, fry emergence, and smoltification (Lower Columbia Fish Recovery Board 2004 as cited in National Marine Fisheries Service 2000).

Since 1938, summer water temperatures at Bonneville Dam have increased 4 degrees on average (Lower Columbia Fish Recovery Board 2004). Among-year variability in temperature has been reduced by 63 percent since 1970 (Lower Columbia Fish Recovery Board 2004). As shown in Figure 3-3, temperatures entering the estuary (as measured at Bonneville Dam) have increased steadily since 1938. Temperatures also exceed 20° C earlier during the year and more frequently than they did historically (National Research Council 2004).

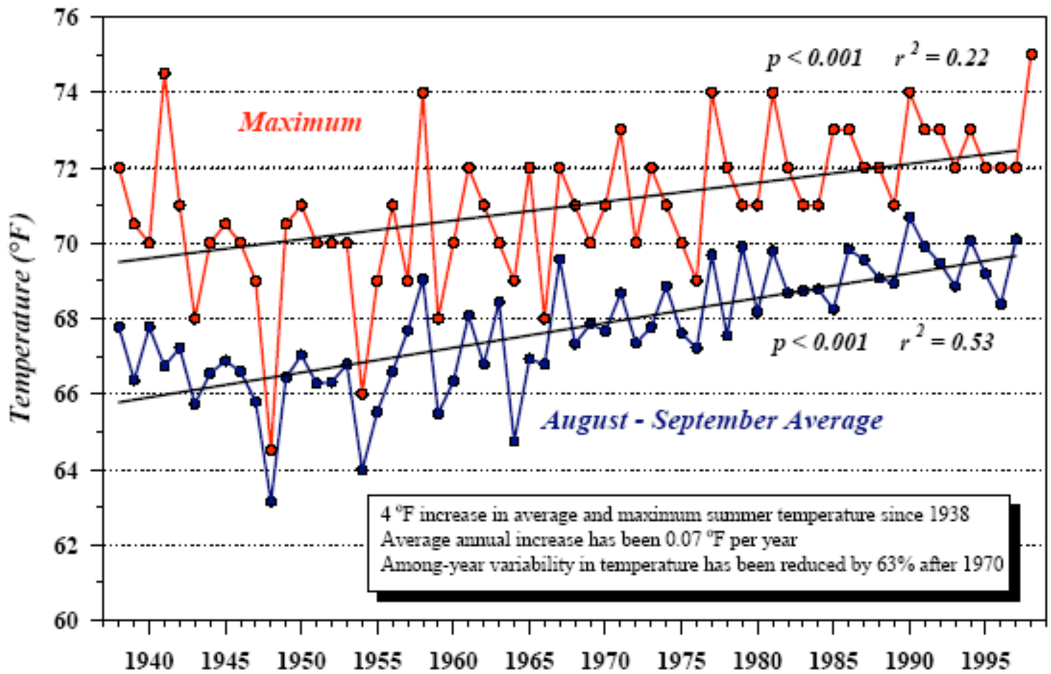

FIGURE 3-2
Temperatures of Water Entering the Estuary
(Reprinted from Lower Columbia Fish Recovery Board 2004.)

Limiting Factor: Stranding

In the estuary, large ships passing through the navigational channel produce bow waves that crash against shorelines in Oregon and Washington. Small ocean-type fry and fingerlings rear within inches of shore and may become stranded as waves intersect the bank and recede (Ackerman 2002), although the extent of this problem is unclear. A 1977 study by the Washington Department of Fisheries (WDF) estimated that more than 150,000 juvenile salmonids—mostly chinook—were stranded at five test sites (Bauersfeld 1977).

A NOAA technical memorandum (Hinton and Emmett 1994) published in 1994 concluded that the problem was not as significant as documented in the WDF report. As part of the channel deepening project being conducted by the U.S. Army Corps of Engineers, a two-part study of stranding was initiated by the University of Washington and the Portland District of the Corps. The study is designed to measure differences in stranding events before and after channel deepening activities. The first study was published in February 2006 (Pearson et al. 2006). In general, the report documents mortality attributed to stranding events for three test sites; it also builds on other recent work to determine the conditions that increase the likelihood of stranding events. No attempt was made to determine an estimate of mortality from this limiting factor for the entire estuary.

Food Web-Related Limiting Factors

Energy released from the Columbia River and the ocean converges in the estuarine, nearshore ocean, and plume environments where, combined with the biological energy of primary plant production, it forms the basis for life in the estuarine ecosystem. Ultimately, energy for the ecosystem begins with sunlight, sunlight leads to plant growth, plants are eaten by animals, and animals eat each other. Energetic processes, then, determine what is being eaten and by whom.

For the past 4,000 years, salmon and other native species have evolved together in response to the basic inputs of energy and their circulation through the ecosystem. The result has been the development of an intricately structured food web in the estuary that encompasses food sources, food availability, and inter- and intra-species relationships. Although stable ecosystems go through cycles of change in energy flows over time, basic energy pathways frequently remain unaltered. As the flow of energy through the ecosystems changes, so do the relationships among species and between species and their habitats. Competition and predation relationships shift and the abundance of species increases or decreases, depending on species' ability to adapt to changing conditions. Changes in any one of the elements of the food web, such as food sources or availability, can ripple throughout the ecosystem and have potentially far-reaching effects on salmonids and other species.

As part of the food web, plant materials known as detritus are consumed by juvenile salmonids, either directly or indirectly through other organisms that feed on the detritus (Northwest Power and Conservation Council 2004). There is evidence that a shift in plant primary production in the estuary—from a macrodetrital to a microdetrital base—has significantly changed the food web and that complex inter- and intra-species relationships have been permanently altered (Northwest Power and Conservation Council 2004). Food web-related conditions that may have reduced the productive capacity of the estuary include reduced foraging habitat, changes in detrital sources, and fine sediment inputs. By disrupting the food web, these conditions have increased competition and predation (Bottom et al. 2005).

Insects also may play a crucial role in maintaining the food web. A recent University of Washington master's thesis demonstrated the importance of midge insects in the diet of juvenile chinook salmon occupying shallow-water habitats in the Columbia River estuary—emerging chironomids were the dominant prey for chinook of all sizes (Lott 2004). The importance of flora that support insect availability in emergent marsh, scrub-shrub wetland, and forested wetlands used by salmonids with ocean-type life history strategies is likely to become an area of greater interest by scientists.

Affected salmonids: Ocean-type ESUs are more likely than stream-type juveniles to be affected by food web alterations because of their use of estuary habitats and their longer residency times. Stream-type ESUs are more influenced in the plume environment because of reduced fine-sediment inputs leaving the estuary.

Food Source Changes

As described below, changes in the detrital sources that form the base of the estuarine food web have been significant and represent a limiting factor for salmonids. Figure 3-2 shows a conceptual model of the estuary food web developed by the U.S. Army Corps of Engineers. The historical tidal marsh macrodetritus-based food web is displayed at the top of Figure 3-2, while the current food web, which is based on imported microdetritus, is shown at the bottom.

Limiting Factor: Reduced Macrodetrital Inputs. The estuarine food web formerly was supported by macrodetrital inputs of plant materials that originated from emergent, forested, and other wetland rearing areas in the estuary (Northwest Power and Conservation Council 2004). Today, detrital sources from emergent wetlands in the estuary are approximately 84 percent less than they were historically (Bottom et al. 2005).

Macrodetrital plant production has declined as a result of the construction of revetments along the estuary shorelines, the disposal of dredged material in what formerly were shallow or wetland areas where plant materials or insects could drop into the water, and reductions in flow. Flow reductions affect detrital sources by limiting the amount of wetlands—areas that normally would be contributing microdetritus to the food web—and cutting the number of overbank flows. Historically, much of the detrital inputs occurred during overbank events, which provided additional shallow-water habitat for juvenile salmonids and resulted in significant detrital inputs to the estuary. As mentioned earlier, overbank events occur much less frequently today than they did historically.

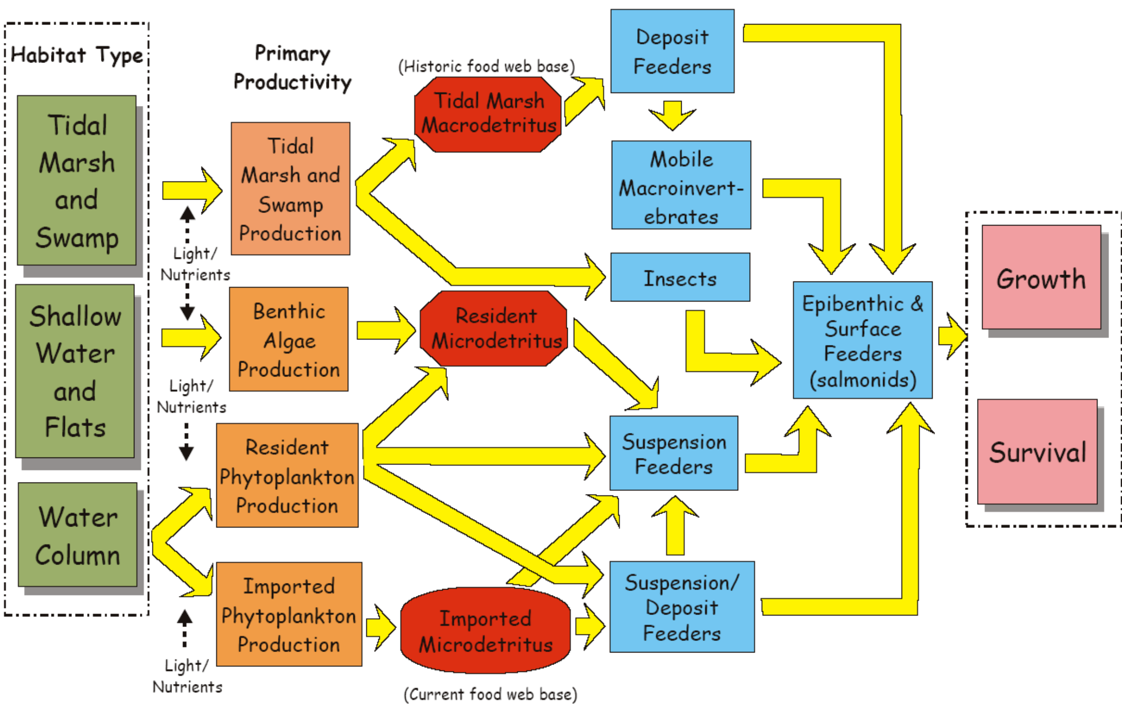

FIGURE 3-3
Conceptual Model of the Columbia River Estuary Food Web

Limiting Factor: Increased Microdetrital Inputs. Instead of being supported by local plant production, the current food web is based on decaying phytoplankton delivered from upstream reservoirs. The amount of this microdetritus has increased dramatically (Bottom et al. 2005). The switch in primary production in the estuary from a macrodetritus-based source to a microdetritus-based source has lowered the productivity of the estuary (Bottom et al. 2005).

The substitution of detrital sources in the estuary also has contributed to changes in the spatial distribution of the food web (Bottom et al. 2005). Historically the macrodetritus-based food web was distributed evenly throughout the estuary, including in the many shallow-water habitats favored by ocean-type salmonids. But the contemporary microdetrital food web is concentrated within the estuarine turbidity maximum in the middle region of the estuary (Bottom et al. 2005). This location is less accessible to ocean-type ESUs that use peripheral habitats and more accessible to species such as American shad that feed in deep-water areas.

Pelagic fish such as shad may also benefit from the fact that the estuarine turbidity maximum traps particles and delays their transport to the ocean up to 4 weeks, compared to normal transport of around 2 days (Northwest Power and Conservation Council 2004). The estuarine turbidity maximum is thought to contain bacteria that attach to detritus. Together these represent the primary food source in the estuary today (Northwest Power and Conservation Council 2004).

Competition and Predation

Predation and competition for habitat and prey resources limit the success of juvenile salmonids entering the estuary and plume. Both spatial and energetic losses can involve either density-dependent or density-independent processes (Bottom et al. 2005). Spatial and temporal losses of habitat and large pulses of hatchery juveniles may, under some conditions, result in density-dependent salmonid mortality (Bottom et al. 2005). Emerging studies in the Skagit River are predicting density-dependent losses to juvenile salmonids in the river delta (Beamer et al. 2005).

Competition among salmonids and between salmonids and other fish may be occurring in the estuary, with the intensity and magnitude of competition depending in part on how long hatchery and natural juvenile salmonids reside in the estuary (Lower Columbia Fish Recovery Board 2004). When large numbers of ocean-type salmonids enter the estuary, it may become overgrazed. Food availability may be reduced as a result of the temporal and spatial overlap of juveniles from different locations, including hatcheries (Lower Columbia Fish Recovery Board 2004 as cited in Bisbal and McConnaha 1998).

Ecosystem-scale changes in the estuary have altered the relationships between salmonids and other fish, birds, and mammals species, both native and exotic. Some native species' abundance levels have decreased from historical levels—perhaps to the point of extinction—while others have increased to levels far exceeding those in recorded history, with associated changes in predation of salmon and steelhead juveniles.

The presence of non-indigenous fish, invertebrates, and plants in species assemblages indicates major changes in aquatic ecosystems (Northwest Power and Conservation Council 2004). Globally the introduction of such species is increasing, a fact that is attributable to the increased speed and range of world trade, which facilitates the transport and release—whether intentional or not—of non-indigenous species (Northwest Power and Conservation Council 2004). In the estuary, the introduction of exotic species has altered the ecosystem through competition, predation, disease, parasitization, and alterations in the food web.

Non-native species affect ocean-type ESUs more than they do stream-type ESUs because of the ocean types' longer juvenile estuary residency times and use of shallow-water habitats.

Limiting Factor: Native Fish. The northern pikeminnow is a native piscivorous fish that preys on juvenile salmonids in the estuary. Although pikeminnows have always been a significant source of mortality for juvenile salmonids in the Columbia River, changes in physical habitats may have created more favorable conditions for predation (Northwest Power and Conservation Council 2004). The diet of pikeminnows varies with age, with the largest adults representing the biggest risk to juvenile salmonids. Ocean-type ESUs are affected more than stream-type ESUs because of their longer estuary residency times and use of shallow-water habitats; however, it is believed that stream-type juveniles are leaving faster, deeper water to forage for food in the shallows and thus may experience mortality as a result of pikeminnow predation.

Limiting Factor: Native Birds. As a result of estuary habitat modifications, the number and/or predation effectiveness of Caspian terns, double-crested cormorants, and a variety of gull species has increased (Fresh et al. 2005). In 1997 it was estimated that avian predators consumed 10 to 30 percent of the total estuarine salmonid smolt production in that year (Northwest Power and Conservation Council 2004). The draft 2005 season summary of *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River* (Collis and Roby 2006) estimates that 3.6 million juvenile salmonids were consumed by terns in 2005. Stream-type juvenile salmonids are most vulnerable to avian predation by Caspian terns because the juveniles use deep-water habitat channels that have relatively low turbidity and are close to island tern habitats. Double-crested cormorants consume a similar number of juvenile salmonids (approximately 3.6 million juveniles) from their East Sand Island nesting grounds (Collis and Roby 2006).

Limiting Factor: Native Pinnipeds. The abundance of native pinnipeds has steadily increased since passage of the Marine Mammal Protection Act in 1972. Harbor seals, Steller sea lions, and California sea lions all prey on salmon and steelhead in the estuary (Northwest Power and Conservation Council 2004). Diet studies indicate that pinnipeds consume both juvenile and adult salmonids. Estimates of mortality that occurs at Bonneville Dam because of sea lions ranged from a low of 0.4 percent in 2002 to a high of 3.4 percent in 2006 (U.S. Army Corps of Engineers 2005). These estimates do not account for pinniped mortality occurring downstream of Bonneville Dam. There are no official estimates of downstream mortality on adult spring chinook and winter steelhead (both of which are stream-type salmonids); however, unsubstantiated estimates are as high as 10 percent, which would equate to about 29,000 adult fish.

Limiting Factor: Exotic Fish. At least 37 exotic fish species are now found in the Columbia River estuary (Northwest Power and Conservation Council 2004). American shad were introduced into the Columbia River in the 1880s, and adult returns now exceed 4 million in a single year (Northwest Power and Conservation Council 2004). While shad do not eat salmonids, they exert tremendous pressure on the estuary food web given the sheer weight of their biomass. Other exotic fish in the estuary, such as smallmouth bass, walleye, and catfish, are piscivorous; however, their abundance levels are relatively small.

Limiting Factor: Introduced Invertebrates*.* Twenty-seven non-native invertebrate species have been observed in the estuary and documented by the Lower Columbia River Aquatic Non-indigenous Species Survey (Sytsma et al. 2004). Recent surveys have documented that the estuarine copepod community has changed from a system dominated by a single introduced species, *Pseuduodiaptomis inopinus*, to a system dominated by two newly introduced Asian copepods: *Pseudodiaptomis forbesi* and *Sinoclaanus doerri* (Santen 2004). In some cases, the abundance of non-native invertebrates can alter food webs through their wide distribution and key role in the food chain (Northwest Power and Conservation Council 2004).

Limiting Factor: Exotic Plants. The introduction of non-indigenous plant species also has altered the estuary ecosystem. Exotic plant species often out-compete native plants, which results in altered habitats and food webs (Northwest Power and Conservation Council 2004). About 18 aquatic plants have been introduced into the estuary since the 1880s (Sytsma et al. 2004). Examples of non-indigenous plant species include purple loosestrife, Eurasian milfoil, parrot feather, and Brazilian elodea. In addition to out-competing native plants, introduced plant species can contribute to poor water quality and create dense, monospecific stands that represent poor habitat for native species (Northwest Power and Conservation Council 2004). In turn, these new plant communities may alter insect and detritus production in and around vegetated wetlands.

Toxic Contaminants

The quality of habitats in the Columbia River estuary is degraded as a result of past and current releases of toxic contaminants (Fresh et al. 2005), from both estuary and upstream sources. Historically, levels of contaminants in the Columbia River were low, except for some metals and naturally occurring substances (Fresh et al. 2005); today, contaminant levels in the estuary are much higher. Currently the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from agricultural and urban sources (Fresh et al. 2005). With the cities of Portland, Vancouver, Longview, and Astoria on its banks, the Columbia River below Bonneville Dam is the most urbanized section of the river.

Sublethal concentrations of contaminants affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes, including reproduction. In juvenile salmonids, contaminant exposure can result in decreased immune function and generally reduced fitness (Northwest Power and Conservation Council 2004).

A recent study by Loge et al. in the Columbia River will likely bring more attention to the effects of contaminants on salmonids in the estuary. The study documents infectious disease in outmigrating juvenile salmonids attributed to abiotic stressors, such as chemicals, that influence host susceptibility to infection. The study estimates delayed disease-induced mortalities in chinook salmon at 3 percent and 18 percent for estuary residence times of 30 to 120 days, respectively (Loge et al. 2005). Other contaminants in the water column, including endocrine-disrupting substances such as synthetic hormones, are only beginning to be characterized in the estuary, but these contaminants could have substantial effects on salmon and steelhead (Fresh et al. 2005).

The exposure of stream-type juveniles to contaminants in the plume is understudied. The Lower Columbia River Estuary Partnership currently is leading an effort to develop a model of contaminant flux in the estuary as it relates to juvenile salmonids. The model will identify natural processes and anthropogenic perturbations that affect the estuarine environment. Initial products should be available toward the end of 2006.

Affected salmonids: It is likely that stream-type juvenile salmonids are most affected by short-term exposure to waterborne contaminants such as organophosphate pesticides and dissolved metals (Fresh et al. 2005). Ocean-type juveniles are affected by short-term exposure, too, but they also experience mortality from bioaccumulative toxicants such as DDT and PCBs that are absorbed during longer estuarine residence times (Fresh et al. 2005).

Limiting Factor: Bioaccumulation Toxicity. Potentially toxic water-soluble contaminants, trace metals, and chlorinated compounds have been observed in the estuary (Fresh et al. 2005).

DDT and PCBs have been detected at elevated levels in juvenile salmonids using the estuary. These substances concentrate in animals near the top of the food chain. In a 2005 study by Loge et al., cumulative delayed disease-induced mortalities were estimated at 3 percent and 18 percent for juvenile chinook residing in the Columbia River estuary for 30 to 120 days, respectively (Loge et al. 2005). Figure 3-4 shows mean concentrations of PCBs and DDTS found in juvenile chinook in several locations of the Columbia River estuary and other Northwest estuaries.

Limiting Factor: Short-Term Toxicity. A variety of organochlorines (including aldrin, dieldrin, trichlorobenzene, and PAHs) in the estuary are above state and federal guidance levels (Northwest Power and Conservation Council 2004). As mentioned above, sublethal concentrations of contaminants can affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes (Northwest Power and Conservation Council 2004). Figure 3-5 shows mean concentrations of PAHs in juvenile fall chinook in various locations of the Columbia River estuary and other Northwest estuaries.

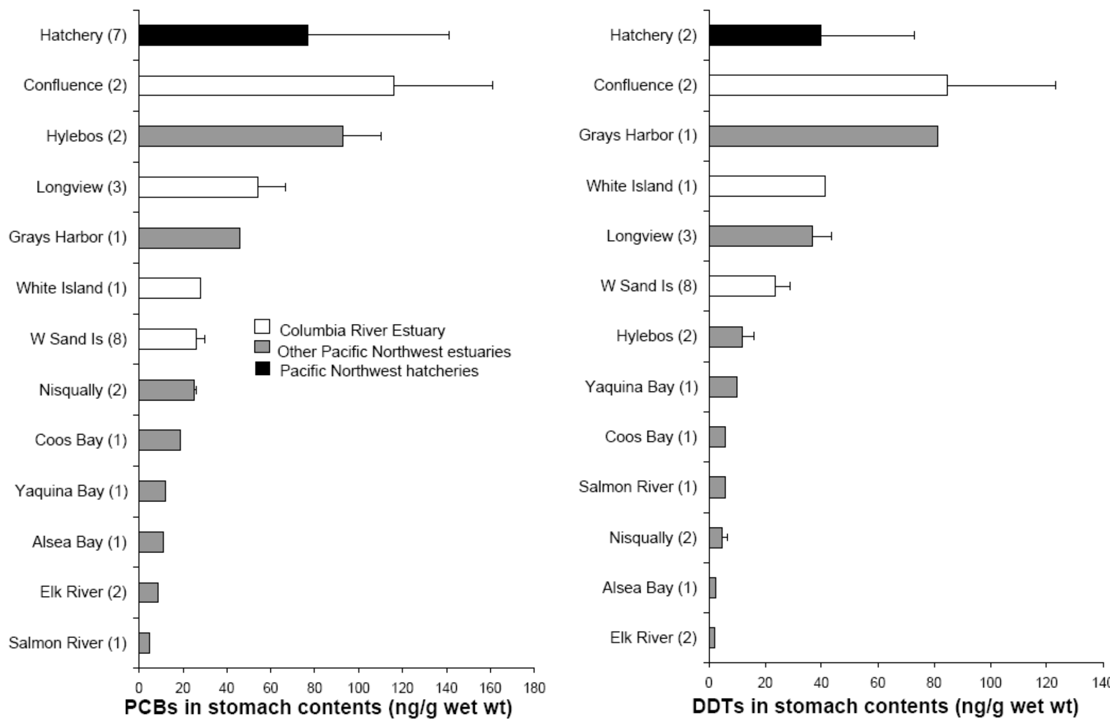

FIGURE 3-4
Mean Concentrations of PCBs and DDTs in Juvenile Chinook
(Reprinted from Fresh et al. 2005.)

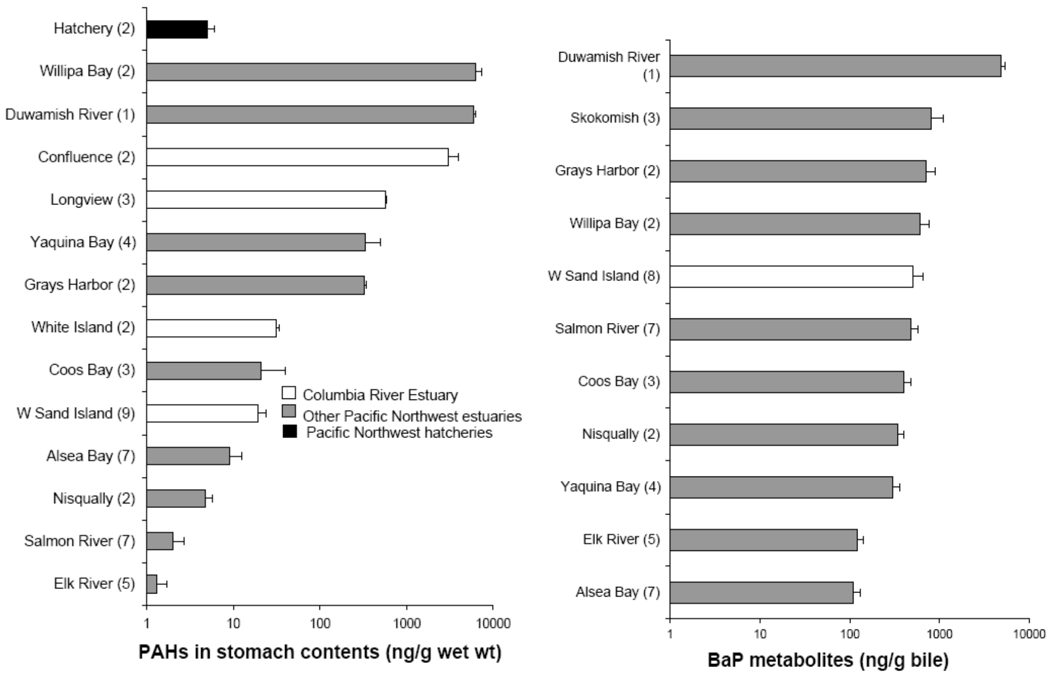

FIGURE 3-5
Mean Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) in Juvenile Chinook
(Reprinted from Fresh et al. 2005.)

Prioritization of Limiting Factors

All three of the primary literature sources used in this estuary recovery module identified flow, sediment, water quality, and food web alterations as limiting factors. In *Salmon at River's End* (Bottom et al. 2005), each of the limiting factor categories is analyzed in the context of habitat opportunity and capacity and how the limiting factor fits within the member/vagrant conceptual framework. In the Fresh technical memorandum, selected limiting factors are evaluated for their impacts on ocean- and stream-type ESUs. Limiting factors selected for analysis in Fresh et al. (2005) are tern predation, toxics, habitat, and flow. Finally, the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" and its supplement (Northwest Power and Conservation Council 2004) evaluate limiting factors for their impacts to salmonids and the level of certainty that the factor is limiting.

This estuary recovery module uses a rating system to prioritize limiting factors by ocean- and stream-type salmon and steelhead. For each limiting factor, a score of 1 to 5 was assigned to both ocean- and stream-type salmonids. These scores were based on a synthesis of the three primary literature sources plus a host of others. An initial rating was performed by PC Trask & Associates with input from the Lower Columbia River Estuary Partnership, NOAA/NMFS's Northwest Fisheries Science Center, NOAA/NMFS – Northwest Regional Office, and the Lower Columbia Fish Recovery Board. Additional reviews were used to refine scores. Although the three primary documents did not refer to stranding as a limiting factor, input from Washington Department of Fish and Wildlife staff was used to research the issue directly from other primary sources.

Table 3-1 shows the results of the limiting factor rating process. Each limiting factor received two scores—one for ocean-type salmonids and one for stream-type salmonids. One simplifying assumption in scoring is that both ocean- and stream-type salmonids express a diversity of life history strategies within ESUs and their constituent populations. Relative scores between ocean- and stream-type generally reflect the dominant life history stage by providing extra weight to the dominant life history strategy; however less dominant strategies are considered. For example, reduced off-channel habitat is primarily a limiting factor for ocean-type juveniles because the dominant life history strategy is subyearlings that use shallow-water habitats extensively to feed and rear. However, some ocean-type populations and subpopulations also express a yearling strategy as part of the overall genetic makeup of the population. As a result, both ocean- and stream-type salmonids received scores (albeit lower) for other less dominant life history strategies. The far right-hand column of the table is the total score, which adds ocean- and stream-type impact scores into a single composite score. The assumption that within healthy ESUs there is expression of less-dominant life history strategies is central to *Salmon at River's End* (Bottom et al. 2005) and the Fresh technical memorandum.

Table 3-2 organizes limiting factors into groups based on total score. Top-priority limiting factors are those that have the greatest impact on both ocean- and stream-type ESUs, while lowest priority limiting factors have the least combined impact to ocean- and stream-type ESUs. An important assumption in the rating system is that all limiting factors had an effect on one or both ESU types.

Summary

The identification of limiting factors in the Columbia River estuary is well supported in a variety of literature sources. Although sources take different approaches to lumping limiting factors together or splitting them apart for the purposes of evaluation, all of the documents generally agree that channel confinement and alterations to flows and sediment have significantly degraded the estuary ecosystem in far-reaching ways. Water quality and food web limiting factors also are well documented.

The interconnectedness of these limiting factors suggests the use of ecosystem-based analysis to understand more exactly their effects on salmonids; however, at this point modeling efforts cannot fully explain the complex relationships among limiting factors.

The next chapter examines human actions and natural events that cause or contribute to the limiting factors described in Chapter 3.

TABLE 3-1
Impact of Limiting Factors on Ocean- and Stream-Type Salmonids

Limiting Factor	Level of Impact		
	Ocean Type*	Stream Type*	Total Score
Habitat-Related Limiting Factors			
Reduced in-channel habitat opportunity			
Flow-related estuary habitat changes	5	3	8
Sediment/nutrient-related estuary habitat changes	4	3	7
Reduced off-channel habitat opportunity			
Flow-related changes in access to off-channel habitat	5	3	8
Bankfull elevation changes	5	2	7
Reduced plume habitat opportunity			
Flow-related plume changes	3	5	8
Sediment/nutrient-related plume changes	2	3	5
Water temperature	5	3	8
Stranding	3	2	5
Food Web-Related Limiting Factors			
Food Source Changes			
Reduced macrodetrital inputs	5	3	8
Increased microdetrital inputs	3	2	5
Competition and Predation			
Native fish	3	2	5
Native birds	2	5	7
Native pinnipeds	2	5	7
Exotic fish	2	2	4
Introduced invertebrates	2	2	4
Exotic plants	2	2	4
Toxic Contaminants			
Bioaccumulation toxicity	4	2	6
Short-term toxicity	4	3	7

*Significance of limiting factor to life history strategy:
1 = No likely effects.
2 = Minor effects on populations.
3 = Moderate effects on populations.
4 = Significant effects on populations.
5 = Major effects on populations.

TABLE 3-2
Limiting Factor Prioritization

Limiting Factor	Limiting Factor Score[a]	Limiting Factor Priority[b]
Flow-related estuary habitat changes	8	Top
Flow-related changes in access to off-channel habitat	8	
Reduced macrodetrital inputs	8	
Water temperature	8	
Flow-related plume changes	8	
Bankfull elevation changes	7	High
Sediment/nutrient-related estuary habitat changes	7	
Native pinnipeds	7	
Short-term toxicity	7	
Native birds	7	
Bioaccumulation toxicity	6	Medium
Increased microdetrital inputs	5	Low
Sediment/nutrient-related plume changes	5	
Stranding	5	
Native fish	5	
Exotic plants	4	Lowest
Introduced invertebrates	4	
Exotic fish	4	

[a]From Table 3-1.
[b]Limiting factors have been prioritized in groups, rather than individually, to avoid a false sense of precision in this qualitative analysis.

CHAPTER 4

Threats to Salmonids

Chapter 4 identifies and prioritizes threats to ESUs in the Columbia River basin. Threats are the human actions or natural events, such volcanic eruptions or floodplain development, that cause or contribute to limiting factors (Gaar 2005). Threats may be caused by past, present, or future actions or events.

The threats presented in this chapter were identified and prioritized using the same process and sources used to identify and prioritize limiting factors—that is, a thorough review and synthesis of pertinent literature (particularly Bottom et al. 2005, Fresh et al. 2005, and Northwest Power and Conservation Council 2004), supplemented by input by area experts. Both limiting factors and threats are well documented in these three key source documents, as well as in a number of other primary sources. In most cases limiting factors and threats are addressed together in the literature, and it required substantial effort to separate them for the purposes of this estuary recovery plan module.

The one threat presented in this chapter that was not mentioned in the main source documents is ship wakes, which can cause stranding of juvenile salmonids. Although the topic of stranding was first raised in a 1977 report (Bauersfeld 1977), the extent of stranding is unclear and the issue has remained quietly controversial and unresolved. The topic is addressed in this recovery plan module at the request of the Washington Department of Fish & Wildlife because ship wakes are speculated to cause significant levels of mortality to ocean-type juveniles (primarily fry).

This chapter organizes threats to salmonids into the following groupings: flow, sediment, structures such as dikes and jetties, ship wakes, food web (including species relationships), and water quality in the estuary. The presentation of threats as discrete activities or phenomena is an oversimplification of complex physical and biological relationships that affect salmon survival. The threats related to flow, sediment transport, and food webs are particularly difficult to tease apart and discuss discretely. Thus the reader should bear in mind that describing threats individually probably does not fully capture the dynamic interplay of forces that are currently putting salmonids in the estuary at risk. The complexity of these forces is illustrated in Figure 4-1, which is a representation of a conceptual model of the Columbia River estuary developed by the U.S. Army Corps of Engineers. The model provides in-depth detail on the relationships between limiting factors and threats.

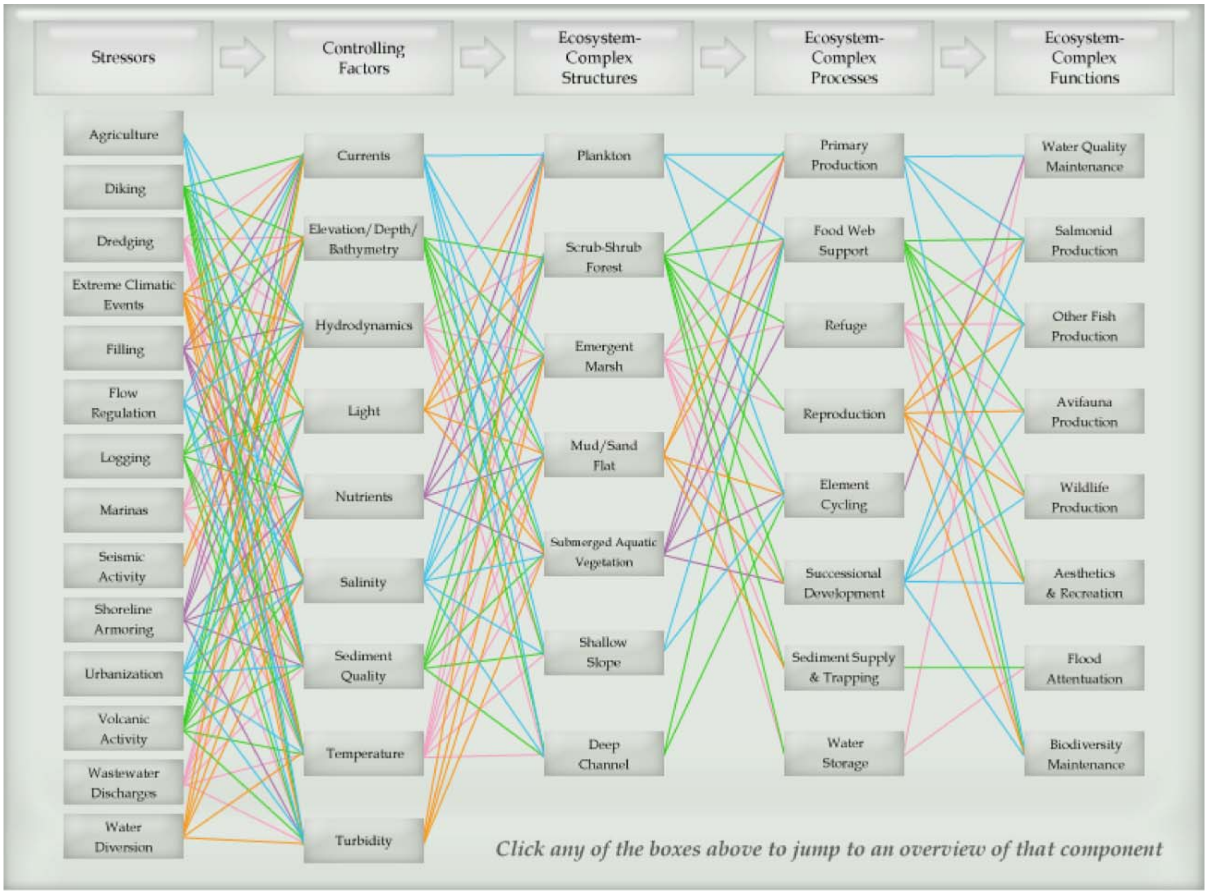

FIGURE 4-1
U.S. Army Corps of Engineers Conceptual Model of the Columbia River Estuary

Most of the human threats described in this chapter are the result of the cumulative impacts of people living in the Northwest. From an ecological perspective these impacts have taken place relatively quickly. Consider that in 1770, when American Robert Gray first crossed the Columbia River bar, about 100,000 Native Americans lived in the Columbia River basin (Oregon State University 1998). Today the population of the Columbia Basin is approximately 5 million (National Research Council 2004). In the early years of Euro-American settlement, the area's abundant natural resources supported farming, mining, logging, fishing, and other activities that modified the landscape into productive uses for people. Later, the availability of cheap hydroelectric power helped fuel expanded agriculture, manufacturing, and development and the rise of urban centers such as Portland. The impacts of these activities on salmonids in the estuary have been substantial.

Flow-Related Threats

Over the last 4,000 years, salmon thrived in the Columbia River by adapting to habitats created by characteristics of the land and water flow (Fresh et al. 2005). Key attributes of flow include magnitude and timing, both of which have changed significantly in the Columbia River over the last two centuries. Today the mean flow to the estuary is about 16 percent less than it was in the latter part of the nineteenth century (Jay and Kukulka 2002), and spring freshet peak flows have declined about 44 percent in that same time period (Jay and Kukulka 2002). In addition, the timing of peak flows occurs about 14 to 30 days earlier than it did historically (Jay and Kukulka 2002). Reductions in the spring freshet flows are shown in Figure 4-2, which presents the annual Columbia River flow cycle measured at the Beaver Army Terminal near Quincy, Oregon, for the periods 1878 to 1903 and 1970 to 1999. The flows for 1878 to 1903 are reconstructed averaged flows.

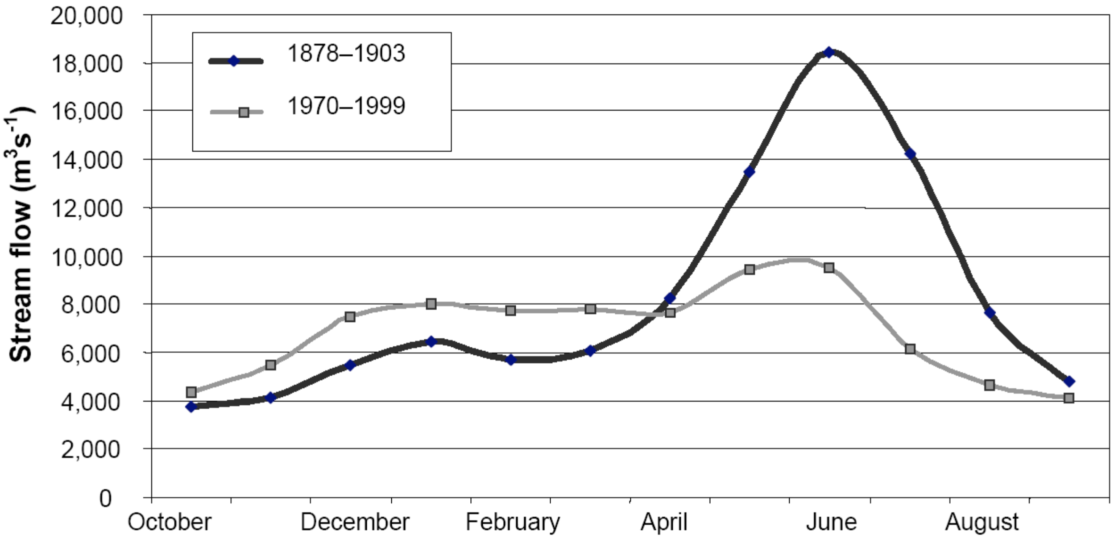

FIGURE 4-2
Changes in the Annual Columbia River Flow
(Reprinted from Bottom et al. 2005.)

Flow alterations, in connection with other factors, can increase or decrease salmonids' ability to access habitats and the capacity of habitats to sustain salmonids (Bottom et al. 2005). In the case of the Columbia River, alterations in the timing, magnitude, and duration of flows are responsible for dramatic changes in habitat opportunity and capacity in the estuary. Climate fluctuations, the withdrawal of water, and regulation of river flow have altered the amount and timing of instream flows entering the estuary and plume.

Affected salmonids: Alterations in the magnitude and timing of Columbia River flows affect both ocean- and stream-type juvenile salmonids. Ocean-type juveniles spend more time in the estuary, where they rely on shallow vegetated swamp and marsh habitats (Northwest Power and Conservation Council 2004). Chum salmon (ocean-type) also spawn in the mainstem and are affected by low flows during the spawning and egg incubation life stages—in extreme cases, redds may be dewatered. Ocean-type salmonids also rely on seasonal overbank flows to access habitats and preferred food sources.

Stream-type juveniles do not spend much time in the estuary, but recent research indicates that they may use the Columbia River plume habitat as they adjust to saltwater conditions (Fresh et al. 2005). Columbia River flows have a direct effect on the plume's surface area, volume, frontal features, and extent offshore (Fresh et al. 2005). Flow alterations also affect sediment transport processes.

Threat: Climate Cycles and Global Warming

Natural variations in Columbia River flow as a result of long- and short-term climate fluctuations have occurred throughout history. The Pacific Decadel Oscillation (PDO) alternates between cold and warm phases approximately every 30 years (Fresh et al. 2005). The cold, rainy phase is typical of the Northwest and increases flows, while the warm phase is drier and decreases flows (Fresh et al. 2005). The El Niño/Southern Oscillation (ENSO) is a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that may magnify or reduce the effects of the PDO. Over the last century, global warming has increased worldwide precipitation by about 1 percent and increased the frequency of extreme rainfall events in much of the United States (U.S. Environmental Protection Agency 2005).

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Over the last 100 years, climatic changes have reduced Columbia River flows by 9 percent (Jay and Kukulka 2002). NOAA/NMFS's Northwest Fisheries Science Center has observed changes in PDO and ENSO indicators that suggest that changes in ecosystem structure can be expected that are unfavorable for salmon and steelhead (Varanasi 2005). These changes are anticipated in late 2005 and may continue over the next several years.

Scientists believe that the release of high levels of carbon dioxide as a result of human activities is responsible for global warming. The source of these releases includes the use of fossil fuels to run cars, heat homes, and power factories. Over the past century, global warming has caused sea levels to rise about 4 to 5 inches (U.S. Environmental Protection Agency 2005). Worldwide precipitation has increased about 1 percent over land over the last 100 years, and the frequency of extreme rainfall events has increased over much of the United States (U.S. Environmental Protection Agency 2005). While global warming is a growing concern, this estuary recovery plan module does not factor it into climate's contribution to flow-related effects in the estuary. However, global warming should receive increasing attention for its potential to affect fish management in the Columbia River basin as a whole.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Threat: Water Withdrawal

Reduction in the amount of instream flow in a river system is an important measure of alterations to the system (Fresh et al. 2005). Water withdrawals affect both the magnitude and timing of flows entering the estuary and plume.

Historically, flow conditions in the estuary were determined by seasonal climate effects (such as precipitation) and hydrology. Since the early 1900s and to a larger degree since the 1960s, irrigation practices have reduced flows in the Columbia River. Water withdrawals as a result of agricultural irrigation and other water uses are estimated to have reduced flows of the Columbia River by 7 percent since the latter part of the nineteenth century (Jay and Kukulka 2002).

Other human activities that reduce flows are the result of upstream use of surface water and groundwater for commercial, industrial, municipal, domestic, and other purposes (National Research Council 2004).

Irrigation withdrawals of surface water account for approximately 96 percent of total water used, while municipal and other uses account for only 4 percent (National Research Council 2004). On the other hand, about 75 percent of all groundwater withdrawals support irrigation and the remaining 25 percent are used for other purposes (National Research Council 2004).

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Threat: Flow Regulation

The timing and magnitude of spring freshets have been drastically altered by management of the Columbia River hydrosystem (Fresh et al. 2005). Jay and Kukulka (2002) estimate that 26 percent of the overall reduction of freshet season flow since the late nineteenth century is attributable to flow regulation. Together with irrigation, flow regulation has increased fall and winter flows (winter flows have increased because of pre-release before the freshet season), and much of the seasonal timing of flows in the estuary can be attributed to flood control and hydroelectric operations.

Flow regulation is a function of the hydrosystem in the United States and Canada. The first hydroelectric facility in the lower Columbia Basin—the T.W. Sullivan Dam in Oregon City—was constructed in 1888. Since then, more than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). These dams supply British Columbia with 50 percent of its electricity, while the American Northwest relies on hydropower for about two-thirds of its electricity (Columbia Basin Trust). Columbia River dams also provide flood control, enhance irrigation, and improve navigation.

The total active storage of water in the Columbia River Basin is 42 million acre-feet (Northwest Power and Conservation Council 2001), with dams in Canada accounting for about half of the total storage (Northwest Power and Conservation Council 2001). Major Canadian dams include the Duncan, Arrow, and Mica dams. Major U.S. hydroelectric facilities with significant storage include the Grand Coulee, Dworshak, Hungry Horse, and Libby dams.

Several recent changes in hydrosystem operations have been implemented to benefit salmonids throughout the basin. These include increasing flows to benefit spring juvenile salmonid migration in the mainstem Snake and Columbia rivers. This action helps flows in real time instead of filling reservoirs. Also, summer flows have been augmented to assist Snake River fall chinook migration. Finally, a minimum flow has been administratively set from November through April to reduce the potential for dewatering of chum redds, primarily in Reach G in the estuary.

High dissolved gas levels associated with dam operations have resulted in significant salmon mortality, especially before the problem was identified and measures taken to reduce its incidence (Ebel 1969 as cited in Lower Columbia Fish Recovery Board 2004). Monitoring shows that salmonid mortality continues to be associated with spill events.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetrital inputs.

Sediment-Related Threats

Changes to seasonal flows, dredging, and the entrapment of sediment in reservoirs have altered those habitat-forming processes in the Columbia River estuary, plume, and nearshore that relate to sediment.

As described in Chapter 3, the transport of sediment is fundamental to habitat-forming processes in the estuary. Sediment also provides important nutrients that support food production in the estuary and plume. And suspended sediments contribute to turbidity, which is an important to salmonids because of the protection it provides from predators. Although the effects of impaired sediment processes on salmonids in the estuary are not fully understood, the magnitude of change and the key role that sediments play in habitat- and food-related processes are significant.

Entrapment of sediment in reservoirs, reduced downstream transport of sediment, and dredging are the primary sediment-related threats to salmonids in the estuary. Ocean-type juvenile salmonids are affected by sediment-related changes in habitat in the estuary. Stream-type juveniles are affected by reduced turbidity (which can increase predation) in deeper waters in the estuary and plume.

Threat: Entrapment of Sediment in Reservoirs

Reduction in water velocity as a result of upstream reservoirs has altered the transport of organics associated with fine sediments such as silt and clay. Fine sediments entering the estuary originate in the upper watersheds of the Snake River (Northwest Power and Conservation Council 2004). Reduced velocities behind upstream reservoirs act as a sink to fine sediments and likely reduce amounts delivered to the estuary (Northwest Power and Conservation Council 2004). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Impaired Sediment Transport

Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly ocean types. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2002). It is likely that the magnitude of change in sand transport affects habitat-forming processes and reduces turbidity, which results in increased predation in the estuary and plume environments.

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Dredging

Dredging and the disposal of sand and gravel have been a major cause of estuarine habitat loss over the last century (Northwest Power and Conservation Council 2004). Currently, three times more sand is dredged from the estuary than is replenished by upstream sources

(Northwest Power and Conservation Council 2004). In addition to causing habitat loss, dredging may have impaired sediment circulation systems in nearshore ocean areas.

Additional losses of vegetated wetlands in the Columbia River estuary are attributable to filling activities, with deposition of dredged materials accounting for most of the filling activities in the estuary (Fresh et al. 2005). Most dredged materials result from maintenance of the shipping channel. Dredged materials are disposed of in-water, along shorelines, or on upland sites; some dredge material disposal sites are shown in the reach maps in Appendix A. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year (Northwest Power and Conservation Council 2004). Dredge fill activities have significantly reduced the availability of wetlands to the river.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and native birds.

Structural Threats

The development of instream and over-water structures has altered circulation patterns, sediment deposition, sediment erosion, and the formation of habitats in the estuary. Examples of instream and over-water structures include jetties, pile dikes, tide gates, docks, breakwaters, bulkheads, revetments, seawalls, groins, and ramps (Williams and Thom 2001). Such structure create favorable conditions for predators such as northern pikeminnow and walleye, and they can reduce circulation in areas outside of the channel. Instream and over-water structures are found in all reaches of the estuary (for locations, see the reach maps presented in Appendix A).

Another structural threat is reservoirs associated with the hundreds of dams in the Columbia River basin. The relatively large surface area of these reservoirs allows increased solar heating of the impounded water, which in turn contributes to high water temperatures downstream in the estuary.

Affected salmonids: Structural threats primarily affect ocean-type juvenile salmonids because of their longer residency time in the estuary and their wider use of off-channel habitats; however, scientists are now hypothesizing that stream-type juveniles forage outside of deeper channels in shallow-water habitats, where they may fall victim to predators that congregate near instream and over-water structures.

Threat: Pile Dikes and Navigational Structures

Construction of the North and South jetties has altered sediment accretion and erosion processes near the mouth of the Columbia River. Sediment accretion in the marine littoral areas adjacent to the mouth has decreased the inflow of marine sediments into the estuary (Northwest Power and Conservation Council 2004), while the extensive use of dike fields and other structures to maintain the shipping channel has affected natural flow patterns. Development of the navigation channel has reduced flow to side channels and peripheral bays (Northwest Power and Conservation Council 2004). Docks, piers, and other structures have altered habitats and created favorable conditions for predators. In addition, saltwater intrusion patterns have been altered and nutrient cycles have been interrupted.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and exotic fish.

Threat: Dikes and Filling

Dikes and filling activities have significantly altered the size and function of the Columbia River estuary. Since the early 1900s, dikes have been built to allow agricultural and residential uses (Fresh et al. 2005). Dikes are thought to have caused more habitat conversion in the estuary than any other human or natural factor (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). The effects of diking on estuarine habitats are directly proportional to elevation, with the greatest impacts on the highest elevation estuarine habitats: forested wetlands, followed by tidal swamps and tidal wetlands. Diking-related impacts to these habitats have reduced their availability to juvenile salmon and steelhead (Thomas 1983, as reported in Northwest Power and Conservation Council 2004). Figure 4-3 shows the various zones found in typical estuaries. The emergent vegetation, diked marsh, shrub wetlands, and forested wetlands are the zones most affected by dike and filling practices (reprinted from Thom 2001). Diked areas and the historical floodplain in the Columbia River estuary are shown in the reach maps presented in Appendix A.

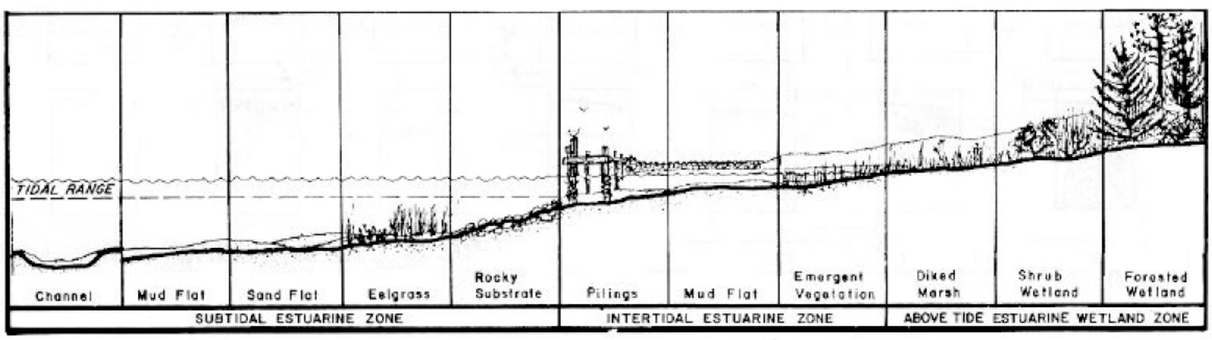

FIGURE 4-3
Subtidal, Intertidal, and Above-Tidal Estuarine Wetland Zones

Before development of the Columbia River hydrosystem and diking and filling, the estuary was dominated by macrodetrital inputs that originated from vegetated wetlands within the estuary. As a result of diking and filling practices and flow alterations (such as changes in the number and timing of spring freshets), emergent plant production in the estuary has decreased by 82 percent and macroalgae production has decreased by 15 percent (Northwest Power and Conservation Council 2004). The availability of insect prey for ocean-type salmonids has been reduced as vegetation has been removed via diking and filling activities and associated dike vegetation maintenance.

Limiting factors this threat contributes to: Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat and plume changes, bankfull elevation increases, and exotic plants.

Threat: Reservoir Heating

More than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). The associated impoundment of water in upstream reservoirs increases the surface area of the Columbia River, allowing more solar heating of river water than occurs in free-flowing river stretches. This solar heating, combined with the reduced flows from upstream impoundments, has contributed to increased water temperatures in the Columbia River. Measurements at Bonneville Dam indicate that periods of increased temperatures are lasting longer than they did historically (National Research Council 2004). Currently, average and maximum values of Columbia River water temperatures are well above 20° C, which approaches the upper limits of thermal tolerance for cold-water fishes such as salmon (National Research Council 2004).

Limiting factors this threat contributes to: Water temperature.

Threat: Over-Water Structures

Over-water structures refer to docks, transient moorage, log rafts, and other structures. These structures block sunlight, reduce flow, and trap sediments downstream of pilings. Over-water structures create microhabitats that may enhance predator habitats, alter circulation patterns, and reduce edge habitats for ocean-type salmonids. Although the actual square footage of over-water structures in the Columbia River estuary has never been inventoried, the structures themselves number in the thousands. Some research has occurred on the effects of breakwaters and over-water structures in the context of marinas. Salmon fry tend to concentrate in higher densities around these structures, thus increasing the risk of predation (Williams and Thom 2001).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, and exotic fish.

Food Web-Related Threats

As described in Chapter 3, changes in the estuarine food web can ripple through the ecosystem, altering feeding patterns, predator/prey relationships, and competition within and among species. The introduction of exotic species such as shad may have accelerated the pace of ecological change in the estuary by permanently altering food webs. Food webs also have been altered by sediment transport, in that microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically.

Affected salmonids: Both stream- and ocean-type salmonids are affected by energy-related threats—stream types primarily through increased predation in deep-water habitats and ocean types primarily through food web changes in the estuary. Ocean-type juveniles also are affected by reduced availability of insect prey as a result of the construction and maintenance of dikes.

Threat: Reservoir Phytoplankton Production

A reduction in macrodetrital inputs has shifted the plant primary production in the estuary to phytoplankton produced in and imported from upstream reservoirs (Northwest Power and Conservation Council 2004). Imported phytoplankton support a pelagic food web that is less accessible to ocean-type salmonids occupying shallow edge habitats (Northwest Power and Conservation Council 2004). The shift in primary plant production from a macrodetrital base to a microdetrital base has provided different food sources than historically existed, in different places within the estuary, that then favor different species.

Limiting factors this threat contributes to: Increased microdetrital inputs.

Threat: Altered Predator/Prey Relationships

Although predation has always occurred in the estuary ecosystem, the cumulative effect of altered flows, changes in sediment transport processes and food sources, introduced species, hatcheries, upstream habitat impacts, hydroelectric impacts, and contaminants have recast estuary and plume environments such that predator/prey relationships have changed significantly. As a result, significant numbers of salmon are lost to fish, avian, and marine mammal predators during migration and residency in the estuary (Northwest Power and Conservation Council 2004). Fish predators include northern pikeminnow, walleye, smallmouth bass, and catfish; avian predators include Caspian terns, double-crested cormorants, and gull species; and marine mammal predators include Steller and California sea lions and harbor seals.

Degraded conditions (loss of habitat and reduced food web productivity) in the Columbia River estuary and the timing of large hatchery releases have increased the likelihood that mortality from competition may occur under some circumstances (Northwest Power and Conservation Council 2004). Mortality from inter-species competition has been documented in the Skagit River estuary (Beamer et al. 2005), and there is speculation that it may be a factor in the Columbia River as well (Northwest Power and Conservation Council 2004). If inter-species competition is occurring, it is likely to have the greatest impact on ocean-type salmonids because of their longer residence time in the estuary (Northwest Power and Conservation Council 2004). If density dependence is affecting stream-type juveniles, it likely happens in the plume.

As the result of human alterations of the estuary environment, native species such as Caspian terns and double-crested cormorants have significantly increased in number, with measurable impacts on stream-type salmonids (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). These increases in population in the Columbia River estuary are attributed to the deposition of dredge materials in the estuary that represent high-quality habitat for the birds (Bottom et al. 2005). The loss of habitat elsewhere has contributed to terns and cormorants effectively relocating to the Columbia River estuary, with the populations there now representing the largest nesting colonies in the world. Similarly, the new microdetritus-based food web in the estuary has benefited zooplanktivores, including American shad (an introduced species) (Northwest Power and Conservation Council 2004). Although shad do not appear to be in direct competition with salmonids, their biomass alone—more than 4 million returning adults a year—represents a threat to trophic relationships in the Columbia River. Other exotic fish species such as introduced walleye and catfish also have been able to capitalize on degraded conditions in the upper reaches of the estuary and alter food web dynamics through predation and competition for food resources. Walleye, for example, prey directly on juvenile salmonids.

Pinniped predation on adult spring chinook and winter steelhead continues to increase. On the West Coast the total abundance of California sea lions is approximately 250,000, Stellar sea lions total about 31,000, and Pacific harbor seals total about 25,000 (Griffin 2006). Each spring about 1,000 Stellar sea lion males, 3,000 Pacific harbor seals, and 800 California sea lions take up residence in the lower estuary (Griffin 2006). A small fraction of the 1,000 Stellar sea lions entering the freshwater (approximately 80) congregate at Bonneville Dam and have been estimated to cause mortality of up to 3.6 percent of all spring chinook and winter steelhead (U.S. Army Corps of Engineers 2005). There are no estimates of the mortality caused by the remaining pinnipeds in the saltwater portion of the estuary and plume or the 200 to 250 Stellar sea lions between Longview and Beacon Rock. Unsubstantiated estimates may exceed 10 percent of the entire adult spring chinook and steelhead runs in a given year.

Non-native plant species have altered habitat and food webs in the Columbia River estuary. The rate of intentional and unintentional introductions has been increasing over the past 100 years, mostly as a result of horticultural practices and the increase in travel and commerce in the Columbia River. Four of those species—purple loosestrife, Eurasian water milfoil, parrot feather, and Brazilian elodea—are of particular concern. Each of these species, in its own way, alters habitat and food webs in the estuary. Purple loosestrife, for example, adapts easily to environmental changes and expands its ranges quickly. The primary ecological effect of purple loosestrife is that it disrupts wetland ecosystems by displacing native plants. Eventually, animals that rely on native flora for food, nesting, or cover also are displaced (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Native birds, native fish, native pinnipeds, introduced invertebrates, exotic fish, and exotic plants.

Threat: Ship Ballast Practices

Ship ballast practices have been responsible for the introduction of at least 21 exotic species in the Columbia River estuary (Sytsma et al. 2004). When ships release ballast water, non-indigenous species can enter receiving waters. Most of the non-indigenous species in the estuary have originated from Asia (Sytsma et al. 2004). Populations of non-native copepods have established themselves in Reaches A and B (Youngs Bay, Cathlamet Bay, and Grays Bay), and the New Zealand mudsnail has colonized other estuary reaches. The Asian bivalve *Corbicula fluminea* has expanded its range in the estuary, with densities of 10,000 per m^2 being recorded in Cathlamet Bay; however, densities of 100 to 3,000 m^2 are more common (Northwest Power and Conservation Council 2004). These and other non-indigenous invaders disrupt food webs and out-compete juvenile salmonids' native food sources.

Limiting factors this threat contributes to: Introduced invertebrates.

Water Quality-Related Threats

The release of toxic contaminants, nutrient loading, and reduced dissolved oxygen have altered the quality of salmonid habitats in the Columbia River estuary. Currently the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from urban and agricultural areas (Fuhrer et al. 1996 as referenced in Fresh et al. 2005). Agricultural, urban, industrial, and timber harvesting practices also affect water quality in the estuary. The literature provides more information about threats related to toxic contaminants than it does about other water-quality issues in the estuary.

Threat: Agricultural Practices

The health of the aquatic ecosystem is substantially affected by agricultural practices and wastewater discharge (National Research Council 2004). Specific threats include increased nutrients (nitrogen and phosphorus), sediment, and organic and trace metals (National Research Council 2004). Agricultural practices in the estuary and throughout the Columbia

River basin contribute water-soluble contaminants and other potentially toxic contaminants. The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) program reports that a wide range of commonly used pesticides have been detected at sampling sites near Bonneville Dam and at the confluence of the Willamette and Columbia rivers (Fresh et al. 2005). Detected water-soluble contaminants include simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl. Arsenic and trace metals such as iron and manganese also have been detected. Although trace metals occur naturally, they also are introduced through human activities, such as the use of lead arsenate as an insecticide for apples (Fresh et al. 2005). Water-soluble contaminants, trace metals, and chlorinated compounds have been detected in the estuary (Fresh et al. 2005), and DDT, PCBs, dioxins, and metals have been detected at elevated levels in tissue from fish in the estuary (Northwest Power and Conservation Council 2004).

Limiting factors this threat contributes to: Short-term toxicity and bioaccumulation toxicity.

Threat: Urban and Industrial Practices

The Columbia River downstream of Bonneville Dam is the most urbanized stretch in the entire basin. The largest sources of effluent in this area are the Portland and Vancouver sewage treatment plants (Fresh et al. 2005). Contaminants also are transported downstream to the estuary from areas above Bonneville Dam. An intensive study of sediments in Portland Harbor (the stretch of the Willamette River from Sauvie Island to Swan Island) has uncovered pesticides, PCBs, and other toxic chemicals. In general, studies have shown that PCB and PAH concentrations in salmon and their prey in the estuary are comparable to those in organisms in other moderately to highly urbanized areas (Fresh et al. 2005). Industrial contaminants such as PAHs have been detected in sediments from the lower Willamette River in Portland at levels that exceed state or federal sediment quality guidelines. The U.S. Environmental Protection Agency recently identified PCB and DDT hot spots within the estuary, including near Longview, West Sand Island, the Astoria Bridge, and Vancouver (Fresh et al. 2005).

Limiting factors this threat contributes to: Short-term toxicity and bioaccumulation toxicity.

Other Threats

Threat: Riparian Practices

Riparian practices along the estuary mainstem and in tributaries throughout the Columbia River basin have contributed to increases in water temperature in the estuary by changing hydrology and removing riparian habitats (National Research Council 2004), which—among other ecological functions—provide insects and macrodetrital inputs to the food web. Problematic practices include shoreline modifications, timber harvest, agricultural activities within buffer zones, and residential, commercial, and industrial land uses. These activities increase water temperatures, alter hydrology and macrodetrital inputs, and in some cases modify shoreline habitats used by salmonids, especially ocean types (Lower Columbia Fish Recovery Board 2004).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, reduced macrodetrital inputs, water temperature, and exotic plants.

Threat: Ship Wakes

Ships traveling through the Columbia River estuary produce waves and an uprush which, under certain circumstances, causes juvenile salmonids and other fish to become stranded on shore (Bauersfeld 1977). Although Bauersfeld concluded that ship wake stranding was a significant cause of mortality in ocean-type chinook salmon and other species, other studies have not confirmed this. As a part of the U.S. Army Corps of Engineers' channel deepening project, a new study is under way that may help characterize the magnitude of ship wake stranding. The purpose of the study is to document ship wake stranding before and after channel deepening. The first half of the study, published in February 2006, documented stranding events at three test sites. The second part of the study will begin after dredging is completed (Pearson et al. 2006). These results should be useful as partial basis for Light Detection and Ranging (LIDAR) analysis and extrapolation of test site mortality throughout the estuary for similar habitat types.

Limiting factors this threat contributes to: Stranding.

Prioritization of Threats

The threats identified above are well supported in a wide variety of literature sources. In many cases, primary literature sources are cross-referenced in the literature and restated and synthesized through comprehensive documents like the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* (Northwest Power and Conservation Council 2004).

The prioritization of threats, though, is not nearly as well supported, partly because of the limited understanding of how threats contribute to limiting factors and to what degree salmon and steelhead are affected by a given limiting factor. While it is attractive to assume that additional study will fully answer these questions, the biological response to environmental conditions will always be difficult to model because of the tremendous complexities of the physical, biological, and ecological interplay that occurs in the environment. On the other hand, new interest in the estuary and its role in the recovery of listed species in the Columbia River has generated better understanding, and it is likely that uncertainty surrounding threats and limiting factors will continue to lessen.

This estuary recovery module establishes priorities for threats by linking them to pertinent limiting factors and estimating their relative contribution to those limiting factors. Literature sources were very useful in making connections between threats and limiting factors. In nearly all cases, authors discussed cause-and-effect relationships in typically qualitative language. In some cases quantitative relationships were established, as in the relationship between flow regulation and sediment transport. Only a handful of sources estimated priorities for either limiting factors or threats.

Table 4-1 links the limiting factors and threats identified in this estuary recovery plan module and estimates the relative contribution of each threat to one or more limiting factors. Although the information presented in the table is oversimplified, given the state of the science the table functions adequately as tool to help identify management actions in Chapter 5.

TABLE 4-1
Linkages Between Limiting Factors and Threats to Ocean- and Stream-Type Salmonids

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
Flow-related estuary habitat changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related changes in access to off-channel habitat	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related plume changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Impaired sediment transport	Top (5)	Primary (3)	15
	Entrapment of sediment in reservoirs	Top (5)	Secondary (2)	10
Reduced macrodetrital inputs	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Riparian practices	Top (5)	Primary (3)	15
	Flow regulation	Top (5)	Primary (3)	15
	Dikes and filling	Top (5)	Primary (3)	15
Water temperature	Reservoir heating	Top (5)	Primary (3)	15
	Riparian practices	Top (5)	Primary (3)	15
Sediment/nutrient-related estuary habitat changes	Impaired sediment transport	High (4)	Primary (3)	12
	Entrapment of sediment in reservoirs	High (4)	Primary (3)	12
	Dredging	High (4)	Tertiary (1)	4
	Pile dikes and navigational structures	High (4)	Secondary (2)	8
	Dikes and filling	High (4)	Primary (3)	12
	Over-water structures	High (4)	Tertiary (1)	4
	Riparian practices	High (4)	Tertiary (1)	4
Bankfull elevation changes	Dikes and filling	High (4)	Primary (3)	12
Short-term toxicity	Agricultural practices	High (4)	Primary (3)	12
	Urban and industrial practices	High (4)	Primary (3)	12

Native birds	Dredging	High (4)	Primary (3)	12
	Altered predator/prey relationships	High (4)	Primary (3)	12
Native pinnipeds	Altered predator/prey relationships	High (4)	Primary (3)	12
Bioaccumulation toxicity	Agricultural practices	Medium (3)	Primary (3)	9
	Urban and industrial practices	Medium (3)	Primary (3)	9
Native fish	Altered predator/prey relationships	Low (2)	Primary (3)	6
Increased microdetrital inputs	Reservoir phytoplankton production	Low (2)	Primary (3)	6
Sediment/nutrient-related plume changes	Dredging	Low (2)	Primary (3)	6
	Pile dikes and navigational structures	Low (2)	Secondary (2)	4
	Dikes and filling	Low (2)	Secondary (2)	4
Stranding	Ship wakes	Low (2)	Primary (3)	6
Introduced invertebrates	Altered predator/prey relationships	Lowest (1)	Tertiary (1)	1
	Ship ballast practices	Lowest (1)	Primary (3)	3
Exotic fish	Over-water structures	Lowest (1)	Secondary (2)	2
	Pile dikes and navigational structures	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3
Exotic plants	Dikes and filling	Lowest (1)	Primary (3)	3
	Riparian practices	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3

[a] From Table 3-2.

[b] Indicates how important the threat is in perpetuating the limiting factor:

3 = Threat is a primary cause of the limiting factor. Addressing this threat would significantly improve salmonid performance.

2 = Threat is a secondary cause of the limiting factor. Addressing this threat would improve performance.

1 = Threat is a tertiary cause of the limiting factor. Addressing this threat would benefit performance, but by itself would result in only minor improvement.

[c] Product of the numerical scores for the limiting factor priority and the threat's contribution to the limiting factor. A high threat index score means that the threat is a major contributor to one or more significant limiting factors. A low threat index score means the threat is a small contributor to a minor limiting factor.

To the degree possible, Table 4-1 demonstrates the relationship between threats and limiting factors by showing which threats are causing which limiting factors and estimating the contribution of each threat to the various limiting factors. The contribution scores in the table were first estimated by PC Trask & Associates by synthesizing information from many literature sources. Scores were then refined through review and input by NOAA/NMFS's Northwest Fisheries Science Center, NMFS staff, Lower Columbia River Estuary Partnership staff, and Lower Columbia Fish Recovery Board staff. Additional review and input will occur from June to October 2006 to help refine and improve the estimates prior to publication in December 2006.

Also in Table 4-1, the contribution of each threat to its associated limiting factor(s) is multiplied by the relative importance of that limiting factor to salmonids (the relative importance of limiting factors is taken from Table 3-2). This yields a threat index score, which expresses the relative priority of the threat in question. Lastly in the prioritization process, Table 4-2 organizes threats by their threat index score, in descending order.

The state of the science is such that the differentiation of threat priorities in Table 4-2 should be viewed as reasonable guidance rather than hard, quantitative data. For example, it is difficult to dispute the importance of flow regulation compared to ship ballast practices. However, given uncertainties about ecosystems and how they function, some lower ranking threats may have tremendous impacts to the estuary in the long run. Continuing the example of ship ballast practices, it is possible that the effects of exotic invertebrates introduced to the estuary through ship ballast practices will significantly degrade the overall health of the estuary ecosystem over time.

Summary

The limiting factors that ocean- and stream-type ESUs encounter in the estuary are a result of upstream and estuary threats. Threats are well-documented in primary and secondary literature sources, although the complexity of interactions at the ecosystem-scale has caused treatment of threats to be inconsistent. New research efforts in the estuary and plume, as in other estuaries around the Northwest, are providing insights into salmonid ecology. For example, a recent University of Washington graduate student gathered data about prey and foraging activities of fall chinook salmon in the estuary and found midge insect prey to be a dominant food source. This raises new concerns about the threat of dikes and filling to ocean-type ESUs that rely on vegetated wetlands for insect prey. In addition, the identification of density-dependent mortality in the Skagit River delta has raised the question of whether density dependence-related mortality is also occurring in the Columbia River estuary. Continued research by NOAA/NMFS's Northwest Fisheries Science Center and monitoring programs like the Lower Columbia River Estuary Partnership contaminant flux model should help reduce uncertainty over time.

The prioritization of threats in Table 4-2 is consistent with contemporary literature sources. Additional review and input from the scientific community in 2006 should help clarify the linkages among threats and limiting factors their significance.

In Chapter 5, management actions are identified and evaluated for their ability to address threats that perpetuate limiting factors, and costs to implement actions are estimated.

TABLE 4-2
Prioritization of Threats to Ocean- and Stream-Type Salmonids

Threat	Threat Index*	Threat Priority
Flow regulation	15	HIGH
Dikes and filling	15	
Reservoir heating	15	
Riparian practices	15	↑
Impaired sediment transport	15	
Entrapment of sediment in reservoirs	12	
Urban and industrial practices	12	
Agricultural practices	12	
Dredging	12	
Altered predator/prey relationships	12	
Climate cycles and global warming	10	
Water withdrawal	10	
Pile dikes and navigational structures	8	
Ship wakes	6	↓
Reservoir phytoplankton production	6	
Over-water structures	4	LOW
Ship ballast practices	3	

* From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

CHAPTER 5

Management Actions

Chapters 3 and 4 of this recovery plan module identify factors that currently limit salmonids' biological performance in the estuary and the threats that contribute to those limiting factors. Chapter 5 presents 23 management actions that, together, address the range of threats salmonids in the estuary face, from altered habitat-forming processes to structures in the estuary, changes in the food web, and poor water quality. If implemented, the actions presented in this chapter would reduce the impacts of threats to salmonids during their migration and residency in the estuary and plume.

In addition to identifying the management actions, Chapter 5 evaluates them in terms of constraints to implementation, potential improvement in salmonid survival, and cost. More specifically, the chapter discusses each management action's potential benefits and implementation constraints, hypothesizes how benefits could translate into increased survival of salmonids, breaks each action into component projects, and estimates the cost of each project, and thus of each action. Also included is a list of actions that would address threats to salmonids in the estuary but that would need to be implemented outside the estuary, in either estuary tributaries or upstream areas of the Columbia River basin.

As in other chapters of this recovery plan module, the analysis in Chapter 5 does not fully capture the subtleties of the ecological interactions that influence salmonid survival. Despite continuing research, many aspects of the salmonid life cycle are poorly understood, in part because of the sheer complexity of the ecosystems that salmonids transition into and out of during their lives. The actual relationships among threats and management actions are far more intricate than what is described here. Additionally, given the limits in scientific understanding, there is a degree of uncertainty at each step of the analysis in this chapter. Yet the categories, ratings, and associations presented here are useful tools for discussing complex ecological relationships and comparing possible outcomes of different management actions.

Identification of Management Actions

For the purposes of this recovery plan module, a management action is any action that has the potential to reduce the impact of human-caused or naturally occurring threats to salmonids while they migrate or rear in the estuary, plume, and nearshore. Management actions were identified using available literature and input from area experts. Key documents used to identify management actions are the "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan" (Northwest Power and Conservation Council 2004) and its supplement, *Role of the Estuary in the Recovery of Columbia River Salmon and Steelhead (*Fresh et al. 2005), *Salmon at River*'s *End*, (Bottom et al. 2005) and the *FCRPS Biological Opinion Remand* (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). Table 5-1 lists threats to salmonids in the estuary and plume and management actions that would address those threats.

Several of the management actions in Table 5-1 are associated with more than one threat (italics indicate an action's second occurrence in the table). This illustrates the complex interplay of ecological processes in the estuary, particularly those related to flow, sediment, the food web, and water quality, all of which influence salmon survival. Again, given the complexity of the riverine, estuarine, and marine ecosystems that salmon use during their lives, the actual relationships among threats and management actions are more complicated than Table 5-1 suggests.

TABLE 5-1
Management Actions to Address Threats

	Threat	Management Action
Flow-related threats	Climate cycles and global warming[2]	**CRE[1]-1:** Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.[2]
		CRE-2: Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.[2]
		CRE-3: Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.[2]
	Water withdrawal	***CRE-3:*** *Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.*
	Flow regulation	**CRE-4**: Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to provide better transport of sediments and access to habitats in the estuary, plume, and littoral cell.
Sediment-related threats	Entrapment of sediment in reservoirs	**CRE-5:** Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.
	Impaired sediment transport	**CRE-6:** Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.
		CRE-4: *Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to provide better transport of sediments and access to habitats in the estuary, plume, and littoral cell.*
	Dredging	**CRE-7:** Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.
Structural threats	Pile dikes and navigational structures	**CRE-8:** Remove pile dikes that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.
	Dikes and filling	**CRE-9:** Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.
		CRE-10: Breach or lower dikes and levees to improve access to off-channel habitats.
	Reservoir heating	***CRE-2:*** *Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.*
	Over-water structures	**CRE-11:** Reduce the square footage of over-water structures in the estuary.

Food web-related threats	Reservoir phytoplankton production	***CRE-10:*** *Breach or lower dikes and levees to improve access to off-channel habitats.*
	Altered predator/prey relationships	**CRE-13:** Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.
		CRE-14: Identify and implement actions to reduce salmonid predation by pinnipeds.
		CRE-15: Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.
		CRE-16: Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.
		CRE-17: Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.
		CRE-18: Reduce the abundance of shad entering the estuary.
	Ship ballast practices	**CRE-19:** Prevent new invertebrate introductions and reduce the effects of existing infestations.
Water quality-related threats	Agricultural practices	**CRE-20:** Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.
	Urban and industrial practices	**CRE-21:** Identify and reduce industrial, commercial, and public sources of pollutants.
		CRE-22: Monitor the estuary for contaminants and/or restore contaminated sites.
		CRE-23: Implement stormwater best management practices in cities and towns.
		CRE-1: *Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.*
Other threats	Riparian practices	***CRE-1:*** *Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.*
	Ship wakes	**CRE-12:** Reduce the effects of vessel wake stranding in the estuary.

[1] CRE = Columbia River estuary.

[2] It is unclear what the regional effects of climate cycles and global warming will be during the coming decades. In the absence of unambiguous data on the future effects of climate cycles and global warming in the Pacific Northwest, this recovery plan module takes a conservative approach of assuming reduced snowpacks, groundwater recharge, and stream flows, with associated rises in stream temperature and demand for water supplies. The climate-related management actions in Table 5-1 reflect this assumption. Although the management actions clearly would not change the threat itself, they have the potential to lessen its impact on salmonids in the estuary. Even if climate cycles and global warming have effects different from those assumed in this document, the management actions that Table 5-1 associates with climate would provide benefits to salmonids by addressing other threats, such as water withdrawal, urban and industrial practices, and reservoir heating. All three of the management actions associated with climate in Table 5-1 are associated with other threats listed in Table 5-1.

Other Recommended Management Actions

In many ways, conditions in the estuary are the sum of conditions throughout the Columbia River basin. Although some threats to salmonids in the estuary originate exclusively in the estuary itself (Caspian tern predation is one example), others are the result of activities in estuary tributaries or in upstream areas; examples of such threats are timber riparian practices and upstream water withdrawals that reduce stream flow in the estuary. Still other threats, such as urban and industrial practices that contribute contaminants to the river, originate in all three areas—estuary, estuary tributaries, and upstream. Because of the geographic scope of these threats, fully addressing them will require effort not just in the estuary but throughout the basin.

When it comes to management actions, though, the geographic scope of this estuary recovery plan module is limited. For the most part the module focuses on management actions that can be implemented within the estuary itself and that will address threats that either originate exclusively within the estuary itself or have a significant in-estuary component. The assumption is that threats originating from outside the estuary are affecting local conditions in tributary and upstream areas and that actions to address these threats will be included in recovery plans being developed for upstream salmonid populations.

Even so, the analysis in Chapters 3 and 4 of this recovery plan module and a review of contemporary literature yielded four management actions that would directly affect threats to salmonids in the estuary yet would need to be implemented almost exclusively outside of the estuary:

- Upgrade up-river irrigation structures using water conservation best management practices (BMPs) to reduce evaporation and conveyance losses and improve estuary instream flows.
- Implement water conservation best management practices for public and private water purveyors.
- Incorporate water availability analysis in land use planning activities to ensure efficient use of water.
- Protect and restore timberland riparian areas for shade and future wood sources.

Because these four actions are outside the geographic scope of the estuary recovery plan module, they are not analyzed in this chapter. Nevertheless, implementation of these four out-of-estuary actions is important to improving the survival of salmonids in the estuary, so it is recommended that the actions be included in recovery plans being developed for upstream areas of the Columbia River basin.

The recommendation of out-of-estuary actions to improve survival in the estuary is another reflection of the interconnectedness of the various ecosystems salmonids use during their life cycles, the power of the river as a connector, and how the effects of problematic upstream activities are manifested—and sometimes magnified—in the estuary.

Evaluation of Management Actions: Constraints to Implementation

Constraints to implementation is a key factor in evaluating management actions and their likely impacts on salmonids. No management action can benefit salmonids if it cannot be implemented, and in many cases the degree of benefit corresponds to the degree of implementation. For this reason, the 23 management actions identified above are evaluated in terms of the constraints to their implementation, which yields information about the actions' likely outcomes and starts to provide a basis for comparing the probable effectiveness of different actions.

For each management action, Table 5-2 summarizes the primary threat and limiting factors that the action addresses and expresses the significance of those threats and limiting factors in terms of a threat index. (The threat index indicates whether the threat is a major contributor to a significant limiting factor or a minor contributor to a minor limiting factor. The index is useful in distinguishing those actions that, even if they were successful, would affect a relatively small number of fish from those actions that, even if they were only partially implemented or partially successful, would have more profound benefits because they would affect a larger number of fish.) Table 5-2 also provides a score for the potential benefit to salmonids in the estuary if the action were fully implemented and a brief rationale for the score.

Assigning a score for potential benefit with full implementation is just the first step in evaluating management actions. In fact, decisions about management actions will be made within a complex social and political context that includes a wide variety of interests, and it is likely that many of the actions will not be able to be implemented fully because of various technical, financial, political, or social obstacles. To address this issue Table 5-2 assigns an implementation constraints score to each management action and briefly explains how various factors could keep the action from being implemented fully.

The table concludes with a score for potential benefit of each action assuming that implementation of the action is constrained. This score is an attempt to identify more realistically what the results of an action would be given the social, political, and financial climate in which management actions will be decided on. Also, the difference in Table 5-2 between potential benefit with full implementation of an action and potential benefit with constrained implementation is helpful in identifying where it might be worthwhile to expend effort to reduce constraints because the benefits under full implementation would be great. This topic is discussed more fully in Chapter 7.

Some measure of caution should be exercised when viewing the results of this evaluation. In particular, scientific literature generally falls short of prescribing discrete actions to address threats, and the literature is even less robust when it comes to evaluating constraints to the implementation of actions.

TABLE 5-2
Constraints to Implementation of Management Actions

Management Action CRE-1:

Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.

Primary threat this action would address		**Riparian Practices.** Riparian areas provide key ecological functions that affect water temperature, the availability of insects, and macrodetrital inputs to the ecosystem. Riparian areas in the lower Columbia River have been degraded by a number of factors, including shoreline modifications, diking and dike maintenance practices, and activities related to the disposal of dredged material.
Associated limiting factors		Water temperature, reduced macrodetrital inputs, and exotic plants.
Threat index[1]	15	This threat is a primary contributor to two top-priority limiting factors (water temperature and reduced macrodetrital inputs) and a tertiary contributor to one additional limiting factor.
Potential benefits with full implementation of action [2]	4	Protecting intact riparian areas and restoring degraded riparian areas in priority reaches would provide significant benefits to salmonids by reducing water temperatures and increasing macrodetrital inputs to the system.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Levels of protection vary across the lower Columbia region. In some cases, cities and counties are protected through regulatory mechanisms such as growth management or shoreline rules. Regulatory tools such as buffer zones along streams can be effective but require broad public support over time. Restoration projects are expensive and can take decades to provide their full benefit to tributaries directly entering the estuary.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-2: Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.		
Primary threat this action would address		**Reservoir heating.** Low-velocity flows and broad surface area exposure in reservoirs increase the temperature of flows in the estuary. Salmonids are cool-water fish that need stream temperatures of 20º C or lower for normal metabolism, growth, disease resistance, and timing of important life functions such as smoltification and adult migration. Salmonids in the estuary are experiencing water temperatures at the upper limit of their tolerance for longer periods and more frequently than they did historically.
Associated limiting factors		Water temperature.
Threat index[1]	15	This threat is a primary contributor to a top-priority limiting factor.
Potential benefits with full implementation of action [2]	4	Given that at many times during the year water temperatures in the estuary are at or above the upper limits of salmonids' thermal tolerance, any lowering of water temperature could provide significant survival benefits. Water temperatures of below 20º C throughout the year would aid salmonids in carrying out essential physiological processes and life functions.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	5	Elevated temperatures that result from reservoir heating are difficult to reduce. Temperatures may be influenced by the volume and speed of flows through the hydrosystem and the source of those flows (some impoundments have cooler water than others do). International treaties, conflicting fish management objectives systemwide, the need for flood control, power management, and other factors constrain management of the hydrosystem to allow cooler flows to enter the estuary.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-3: Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.		
Primary threat this action would address		**Water withdrawal.** Instream flows in the estuary are important for salmonids because they maintain habitat-forming processes and conditions in the estuary and plume. Although some instream flows have been established in the Columbia River basin tributaries, others are needed, especially with the growing human population in the basin.
Associated limiting factors		Flow-related estuary habitat changes, flow-related changes in access to off-channel habitat, flow-related plume changes, and reduced macrodetrital inputs.
Threat index[1]	10	This threat is a secondary contributor to four top-priority limiting factors.
Potential benefits with full implementation of action [2]	2	Instream flow laws legally protect tributary and mainstem flows. These water rights have legal standing and are senior to predecessor water rights. Establishing legal instream flows for the estuary would protect minimum flow levels in the estuary and plume and support associated habitat-forming processes.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings); stream-type salmonids in the plume.
Implementation constraints[3]	3	The process of setting instream flows is challenging, often takes years, and is not always successful. Implementation of this action would require the involvement of multiple stakeholders, including irrigation, hydrosystem operation, commercial, industrial, tribal, federal, state, and local interests, plus a significant amount of public involvement.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-4: Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to improve access to habitats and provide better transport of sediments in the estuary, plume, and littoral cell.		
Primary threats this action would address		**Flow regulation and impaired sediment transport.** The magnitude, frequency, and timing of flows are an important determinant of habitat opportunity for salmonids in the estuary. Salmonids have adapted to historical flows and depend on them to complete their life cycles. The transport of sand and gravel from upstream and estuary sources helps maintain salmonid habitats, contributes to turbidity that shelters salmonids from predation, and influences food sources in the plume. Spring freshets are important habitat-shaping events for the estuary, plume, and littoral cell.
Associated limiting factors		Flow-related estuary habitat changes, flow-related changes in access to off-channel habitat, flow-related plume changes, reduced macrodetrital inputs in the estuary, and sediment/nutrient-related estuary habitat changes.
Threat index[1]	15	This threat is a primary contributor to several top-priority limiting factors.
Potential benefits with full implementation of action [2]	5	Return to a more natural hydrograph would have significant ecosystem benefits and would affect all facets of salmonid life histories expressed in the estuary and plume. Adjustments to the timing, magnitude, and frequency of flows entering the estuary would be likely to have synergistic effects that would increase the benefit of many of the other actions.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies; stream-type juveniles rearing in the plume.
Implementation constraints[3]	5	Constraints on hydrosystem operations prevent the return to a natural hydrograph in the estuary. Implementation of this action would be limited by international treaties, the need for flood control, fish management objectives systemwide, and power management.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-5: Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.		
Primary threat this action would address		**Entrapment of sediment in reservoirs.** Fine sediment, sand, and gravel are deposited behind slow-velocity impoundments in the Columbia River, and their transport into the estuary, plume, and littoral cell has been reduced. This alters habitat-forming processes and reduces turbidity that otherwise would shelter salmonids from predation.
Associated limiting factors		Flow-related plume changes and sediment/nutrient-related estuary habitat changes.
Threat index[1]	12	This threat is a contributor to both top-priority and high-priority limiting factors.
Potential benefits with full implementation of action [2]	3	Sediment transport processes are important determinants of estuary, plume, and littoral habitats. Effective mitigation of this threat would provide shallow-water habitats, reduce predation of salmonids in the main channel and plume, and strengthen habitat-forming processes.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[3]	5	There are no apparent technical solutions to this threat. Mitigation is recommended, but research is needed to identify the magnitude of the threat and potential solutions or mitigation measures.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-6: Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.		
Primary threat this action would address		**Impaired sediment transport.** The transport of sand and gravel from upstream and estuary sources helps maintain salmonid habitats, contributes to turbidity that shelters salmonids from predation, and influences food sources in the plume. While there are many potential beneficial uses of dredged materials—including enhanced nourishment of the littoral cell, land creation, property stabilization, and out-of-stream uses—there is also potential for using sand for habitat creation within the estuary.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes and flow-related plume changes.
Threat index[1]	12	Although impaired sediment transport is a primary contributor to a top-priority limiting factor (flow-related plume changes), this management action is likely to have its greatest effect in addressing sediment/nutrient-related estuary habitat changes, a high-priority limiting factor; thus it has a threat index of 12.
Potential benefits with full implementation of action [2]	4	The beneficial use of sand resulting from dredge activities could play an important role in restoring habitat capacity and habitat opportunity in the estuary, plume, and littoral cell. The beneficial use of dredged materials to provide sand nourishment could reduce the effects of ship wake stranding, improve habitat for *Corphium* (a food source for salmonids), and be beneficial in the development of emergent marshes and other salmonid habitat features. Sand entering the plume could also have important ecological benefits.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings). This particularly applies to ocean-type juveniles because of their significant use of the nearshore environment.
Implementation constraints[3]	2	Beneficial uses of dredged materials, such as through littoral cell sand nourishment and direct beach nourishment, are currently receiving significant attention, The most obvious constraint to implementation is identifying funding sources to pay for activities beyond the minimum required by law.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-7: Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.		
Primary threat this action would address		**Dredging**. Annual dredge operations maintain a navigational channel that concentrates flows, alters tidal influences, reduces circulation patterns around the estuary, and releases toxic contaminants from substrates. Dredging activities can result in deposited contaminants being disturbed and redistributed throughout the estuary and littoral cell.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes, native birds, and sediment/nutrient-related plume changes.
Threat index[1]	4	As it relates to this action, dredging is a tertiary contributor to a high-priority limiting factor (sediment/nutrient-related estuary habitat changes) and thus has a threat index of 4.
Potential benefits with full implementation of action [2]	2	Continued dredge operations represent a physical change to the Columbia River estuary. However, reducing or mitigating the effects of dredging would improve habitat-forming processes that would benefit salmonids.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Dredging activities have been occurring since the 1870s to provide sufficient draft for ships entering the Columbia River and will continue into the foreseeable future. Ongoing maintenance is needed to keep the channel to specifications for ships, and additional dredging will be conducted in the estuary as part of the channel deepening process. Maintaining the navigation channel requires dredging and disposal of large volumes of material (4 to 5 million cubic yards) each year. Changing dredging equipment and practices to reduce entrainment and habitat effects would be expensive.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-8: Remove pile dikes that have low navigational value but high impact on estuary circulation or juvenile predation effects.		
Primary threat this action would address		**Pile dikes and navigational structures**. Extensive use of pile dikes and navigational structures has altered sediment accretion and erosion processes and reduced flow circulation through shallow-water habitats in the estuary. Pile dikes and other structures also have created favorable conditions for predators of salmonids.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes, sediment/nutrient-related plume changes, and exotic fish.
Threat index[1]	8	This threat is a secondary contributor to a high-priority limiting factor (sediment/nutrient-related estuary habitat changes) and two low-priority limiting factors.
Potential benefits with full implementation of action [2]	3	Removing many instream structures would improve circulation in shallow-water habitats and eliminate some salmonid predator habitats.
Affected salmonids		Ocean-type salmonid; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Only some of the thousands of pile dikes and navigational structures in the Columbia River estuary are necessary to maintain the shipping channel or protect property. Removal of superfluous structures generally is restricted only by cost and would be unlikely to affect property rights or the shipping industry. In cases where pile dikes that do aide in navigation are removed, constraints to implementation would include the cost for additional dredging to maintain the channel.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

***Management Action CRE-9*:** Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.		
Primary threat this action would address		**Dikes and filling.** High-quality off-channel habitat provides crucial feeding, rearing, and refuge opportunities for juvenile salmonids and supplies macrodetrital inputs to the estuarine food web. Reduced floodplain inundation has limited juvenile salmonids' access to historical wetland and swamp habitat, much of which has been converted to other land uses. Protecting remaining intact and accessible off-channel habitats is critical to maintaining key habitats and food sources for juvenile salmonids.
Associated limiting factors		Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants.
Threat index[1]	15	This threat is a primary contributor to both top-priority and high-priority limiting factors.
Potential benefits with full implementation of action [2]	5	Protection of high-quality off-channel areas would help maintain important wetland habitats and supply macrodetrital inputs to the food web and insect food sources for juvenile salmonids—a main component of their diet.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Regulatory programs often do not effectively protect floodplains from conversion to other uses. The acquisition of land for habitat protection remains controversial in the estuary. Rural county governments see land disappearing off tax rolls and also listen to citizen disapproval of public ownership of land. Land acquisition is expensive and depends on the willingness of landowners to sell. The fact that many habitats already have been converted to other land uses limits opportunities to protect high-quality off-channel habitat.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-10: Breach or lower dikes and levees to improve access to off-channel habitats.		
Primary threat this action would address		**Dikes and filling.** Many juvenile salmonids rely on off-channel habitats for feeding and refuge opportunities. Historically, insects and macrodetritus from these habitats were important inputs to the estuarine food web. Dikes, levees, tide gates, and filling have limited the amount and accessibility of key off-channel habitats by reducing floodplain inundation and allowing conversion of land to agricultural, residential, and industrial uses.
Associated limiting factors		Reduced macrodetrital inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants.
Threat index[1]	15	This threat is a primary contributor to both top-priority and high-priority limiting factors.
Potential benefits with full implementation of action [2]	5	Restoring off-channel areas would reclaim habitat that is important to salmonids. In most cases, project benefits would accrue over relatively long periods of time.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	4	Opportunities to restore off-channel habitats are limited because many such habitats already have been filled with dredge materials. Breaching or lowering dikes and levees or removing tide gates often requires the cooperation of multiple landowners and may fundamentally alter land uses. The associated habitat restoration is expensive.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-11: Reduce the square footage of over-water structures in the estuary.		
Primary threat this action would address		**Over-water structures.** Over-water structures may provide habitats for predators and affect instream and shoreline plant communities. However, the total surface area of over-water structures in the estuary has not been quantified and the structures' case-by-case functions have not been analyzed.
Associated limiting factors		Sediment/nutrient-related estuary habitat changes and exotic fish.
Threat index[1]	4	This threat is a tertiary contributor to a high-priority limiting factor (habitat changes) and a secondary contributor to one of the lowest priority limiting factors (exotic fish).
Potential benefits with full implementation of action [2]	3	Given the uncertainty about how much of a threat over-water structures actually pose to salmonids, the potential improvement in survival must be considered low pending additional research and analysis.
Affected salmonids		Ocean-type salmonids (because of their preference for the shallow-water habitats where most structures are located); stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	It is assumed that some over-water structures are more important than others and that removing superfluous or less useful structures would not have deleterious effects on adjacent land uses. Removal of over-water structures that are in currently use would likely require compensation. In some cases, structures such as log rafts could be relocated.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-12: Reduce the effects of vessel wake stranding in the estuary.		
Primary threat this action would address		**Ship wakes.** Wakes from deep-draft vessels traveling through the estuary wash subyearling salmonids onto shore, leaving them stranded. Factors that affect stranding include beach slope and time of day as well as vessel draft, speed, and hull design.
Associated limiting factors		Stranding.
Threat index[1]	6	This threat is a primary contributor to a low-priority limiting factor.
Potential benefits with full implementation of action [2]	3	The extent of mortality caused by ship wake stranding is unknown. Studies in 1977 and 1994 (Bauersfeld 1977, Hinton and Emmett 1994) reached different conclusions, using different approaches. A soon-to-be-released study by the University of Washington and U.S. Army Corps of Engineers may provide further clarification of the issue.
Affected salmonids		Ocean-type salmonids (because of their longer estuarine residency times, their relatively small size, and the habitats they prefer); stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	4	Options for reducing the effects of vessel wake stranding are limited. Ship traffic through the estuary will continue, ship hull design is unlikely to change, and the speed of ships traveling the estuary may be difficult to alter. Modification of some habitats may be necessary to reduce this threat and would likely be expensive.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-13: Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.		
Primary threat this action would address		**Altered predator/prey relationships.** Introductions of smallmouth bass, walleye, and channel catfish in the freshwater reaches of the estuary have increased predation on juvenile salmonids, as have in-water structures that offer predation opportunities for pikeminnow.
Associated limiting factors		Native fish and exotic fish..
Threat index[1]	6	This threat contributes to many limiting factors, although the management action addresses only the native and exotic fish limiting factors, which have a threat index of 6 and 2, respectively.
Potential benefits with full implementation of action [2]	2	Ecosystem alterations in the estuary as a result of pikeminnow, smallmouth bass, walleye, and channel catfish are uncertain. Scientists speculate that pikeminnow may be preying on both ocean- and stream-type juveniles. Maintaining warm-water species at or below current levels would have minor benefits to salmonids by reducing predation and competition.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	2	Although the introduction of exotic fish to the estuary may be irreversible, there are viable tools for managing pikeminnow, smallmouth bass, walleye, and channel catfish; these include habitat management and less restricted harvest management. It is likely that warm-water fishers would actively support maintaining the abundance of these species at current—rather than reduced—levels.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-14: Identify and implement actions to reduce salmonid predation by pinnipeds.		
Primary threat this action would address		**Altered predator/prey relationships.** Pinniped predation on salmonids at Bonneville Dam has been estimated at from 0.5 percent to 3.4 percent of the spring chinook and winter steelhead runs. Estuarywide estimates are unsubstantiated, but it is likely that losses exceed 10 percent of the runs each spring. The extent of predation needs further study and documentation.
Associated limiting factors		Native pinnipeds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to native pinnipeds.
Potential benefits with full implementation of action [2]	3	Actions to reduce predation by pinnipeds would be likely to have only minor impacts on salmonid survival, depending on how many adults are actually being eaten by pinnipeds—a question that remains controversial.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[3]	4	Methods for reducing salmonid predation by pinnipeds are limited because pinnipeds are protected under the Marine Mammal Protection Act. It could take years to amend the act to allow additional pinniped management tools. Non-lethal methods have been only minimally successful, although it is possible that additional testing would identify effective non-lethal methods.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-15: Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.		
Primary threat this action would address		**Altered predator/prey relationships.** Exotic plants in the estuary often out-compete native plants and change the structure of plant communities. The resulting habitat frequently does not provide the same food or shelter that other species, including salmonids, have adapted to over time.
Associated limiting factors		Exotic plants.
Threat index[1]	3	This threat contributes to many limiting factors, although the management action relates only to exotic plants, one of the lowest priority limiting factors.
Potential benefits with full implementation of action[2]	2	Preventing and controlling noxious weeds would help maintain the estuarine food web and habitats that juvenile salmonids rely on.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	Controlling existing infestations of certain species is functionally impossible once the species are established. Although landowners are the most important agents in preventing and controlling exotic plant infestations, landowner education is a significant task that requires a large effort.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-16: Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.		
Primary threat this action would address		**Altered predator/prey relationships.** Caspian tern predation represents a significant source of mortality for stream-type juveniles migrating to saltwater. Stream-type salmonids are particularly vulnerable because of the timing of their out-migration (during tern nesting season) and their preference for deep-channel habitats near tern nesting sites.
Associated limiting factors		Native birds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to Caspian terns.
Potential benefits with full implementation of action [2]	4	Reducing tern predation could have significant effects on the survival of stream-type salmonids, as terns have been documented to consume as much as 3 percent of stream-type juveniles migrating through the estuary.
Affected salmonids		Stream-type salmonids; ocean-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	3	Recent management efforts have helped reduce mortality by relocating terns to nearby habitats. Long-term solutions will require habitat improvements elsewhere for Caspian terns.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-17: Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.		
Primary threat this action would address		**Altered predator/prey relationships.** Predation by double-crested cormorants represents a significant source of mortality for stream-type juveniles migrating to saltwater.
Associated limiting factors		Native birds.
Threat index[1]	12	This threat contributes to many limiting factors, although the management action relates only to double-crested cormorants.
Potential benefits with full implementation of action [2]	4	Recent studies indicate that double-crested cormorants prey on salmonid juveniles in the estuary at a rate equal to or greater than the rate by Caspian terns. In some years cormorants may consume as many as 6 million juveniles.
Affected salmonids		Ocean- and stream-type juvenile salmonids are preyed upon by double-crested cormorants with some fluctuation from year to year. In 2004 double-crested cormorants consumed approximately 4 million subyearling chinook.
Implementation constraints[3]	4	Double-crested cormorants are more difficult to relocate than Caspian terns. Techniques such as the use of decoys and audio playback have not been as effective compared to terns. Perch habitats are plentiful enough in the estuary that removal of pile dikes and other structures may not be an effective tool.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-18: Reduce the abundance of shad entering the estuary.		
Primary threat this action would address		**Altered predator/prey relationships.** Shad returns to the Columbia River number approximately 4 million annually. Shad's effects on the estuary ecosystem and salmonids are poorly understood. However, shad are an introduced species and their biomass alone represents a threat to trophic relationships in the Columbia River.
Associated limiting factors		Exotic fish.
Threat index[1]	3	This threat contributes to many limiting factors, although the management action relates only to shad.
Potential benefits with full implementation of action [2]	2	The impacts of shad in the estuary are unclear. However, it is likely that reducing shad numbers would have some benefits for salmonids.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	5	Shad are thought to have permanently altered the estuary ecosystem, and their complete removal from the estuary is neither practical nor feasible. Effective management tools to limit shad productivity in the Columbia River basin currently are not available. Research is needed in the near term to determine the significance of this threat and identify potential management actions to manage the abundance of shad.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-19: Prevent new introductions of invertebrates and reduce the effects of existing infestations.		
Primary threat this action would address		**Ship ballast practices.** Ship ballast water is responsible for the introduction of exotic invertebrates in the estuary. The effects of these introductions are poorly understood, but it is likely that exotic invertebrates disrupt food webs and out-compete juvenile salmonids' native food sources.
Associated limiting factors		Introduced invertebrates.
Threat index[1]	3	This threat is a primary contributor to one of the lowest priority limiting factors.
Potential benefits with full implementation of action [2]	2	Reducing the impacts of exotic invertebrates would help maintain traditional salmonid food sources and the trophic relationships that salmon have adapted to.
Affected salmonids		Ocean-type salmonids; stream-type salmonids displaying less dominant life history strategies (e.g., early and late fingerlings and subyearlings).
Implementation constraints[3]	5	Improvements in ship ballast practices have already been implemented by the industry as a result of new regulations, and stricter regulations are currently being debated at the federal level. However, there are inherent challenges in managing ballast water that contains organisms from other ecosystems. Also, once exotic invertebrates have been introduced, they represent a permanent alteration of the ecosystem and opportunities to reduce their effects may be few. Current understanding of how the estuary ecosystem is affected by introductions of exotic invertebrates is very limited.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-20: Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.		
Primary threat this action would address		**Agricultural practices.** Water-soluble contaminants such as simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl enter the estuary as a result of tributary and upstream agricultural practices. DDT and PCBs have been detected at elevated levels in the estuary. These and other agricultural contaminants can cause salmonid mortality through bioaccumulation or short-term toxicity.
Associated limiting factors		Short-term and bioaccumulative toxicity.
Threat index[1]	12	This threat is a primary contributor to a high-priority limiting factor (short-term toxicity) and a medium-priority limiting factor.
Potential benefits with full implementation of action[2]	3	Reducing the level of pesticides and herbicides in the estuary would improve survival by reducing ocean-type salmonids' acute and chronic exposure to toxic contaminants and stream-type salmonids' acute exposure.
Affected salmonids		Ocean- and stream-type salmonids.
Implementation constraints[3]	2	Impacts from pesticides and fertilizers have lessened dramatically since the 1950s as a result of new application technologies, new products, and better understanding and regulation of these toxins. Best management practices offer additional ways to reduce the impacts of pesticides and fertilizers. The integration of new practices can be expensive and time-consuming and also can influence the economics of a particular crop.
Potential benefits with constrained implementation of action	2	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-21: Identify and reduce industrial, commercial, and public sources of pollutants.		
Primary threat this action would address		**Urban and industrial practices.** The estuary has been affected by historical and current releases of toxic contaminants, including industrial and commercial pollutants such as PCBs and PAHs. These substances have been found near Portland, Vancouver, Longview, and Astoria. Recent studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants.
Associated limiting factors		Short-term toxicity and bioaccumulation toxicity.
Threat index[1]	12	This threat is a primary contributor to high- and medium-priority limiting factors.
Potential benefits with full implementation of action [2]	4	Reducing sources of pollutants would lower water temperature, nutrient loading, and the amount of toxic contaminants in the estuary. This would improve both habitat capacity in the estuary and the fitness level of salmonids.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[3]	4	While some discharges of industrial and commercial pollutants are permitted, others are not. Efforts to reduce industrial and commercial pollutants are already under way, and there is potential to reduce point-source emissions. Efforts to reduce sources of pollutants are expensive and time-consuming and often have a negative economic effect on operations.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-22: Monitor the estuary for contaminants and/or restore contaminated sites.		
Primary threat this action would address		**Urban and industrial practices.** The estuary has been affected by historical and current releases of toxic contaminants, including industrial and commercial pollutants such as PCBs and PAHs. These substances have been found near Portland, Vancouver, Longview, and Astoria. Recent studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants. The action is intended to address the need to monitor the entire estuary for contaminants; however, actual restoration activities are feasible only in specific reaches.
Associated limiting factors		Short-term toxicity and bioaccumulation toxicity.
Threat index[1]	12	This threat is a primary contributor to high- and medium-priority limiting factors.
Potential benefits with full implementation of action [2]	4	Reducing toxic contaminants in the estuary would improve both habitat capacity and the fitness level of salmonids.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[3]	4	Monitoring activities are already occurring; however, actual restoration of contaminated sites is expensive and technically challenging in many cases. In some cases, restoration may not be feasible or practical.
Potential benefits with constrained implementation of action	3	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Management Action CRE-23:

Implement stormwater best management practices in cities and towns.

Primary threat this action would address		**Urban and industrial practices.** Municipal stormwater runoff can convey toxic contaminants to the estuary, reduce groundwater recharge, and increase the "flashiness" of stream flows. Although cities and towns in the Columbia River basin generally have programs to reduce the impacts of stormwater runoff, stormwater best management practices have not been universally implemented throughout the basin.
Associated limiting factors		Short-term toxicity and bioaccumulation toxicity.
Threat index[1]	12	This threat is a primary contributor to high- and medium-priority limiting factors.
Potential benefits with full implementation of action[2]	2	Implementing stormwater best management practices would markedly improve conditions and provide a net benefit to salmonids in the estuary through a more normal hydrograph, reduced exposure to contaminants, and lower water temperatures.
Affected salmonids		Ocean- and stream-type salmonids (particularly ocean types because of their longer residency in the estuary).
Implementation constraints[3]	2	Some cities lack the resources or will to implement or enforce stormwater best management practices. The benefits of improved stormwater practices generally are associated only with new development and do not offset the full impact of the impervious surfaces in those developments, or the existing impervious surfaces in areas that have already been developed.
Potential benefits with constrained implementation of action	1	

[1] From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

[2] Estimate of the expected benefits to salmonids (ocean- and stream-types combined) if the action were fully implemented.
1 = very low benefits.
5 = very high benefits.

[3] Indicates the feasibility of implementing the action.
1 = significant potential for implementation.
5 = significant constraints to implementation.

Table 5-2 estimates the potential of each management action to benefit salmonids under two different implementation scenarios. Assuming that few of the actions will be able to be implemented fully, which management actions would be likely to result in the greatest survival improvements?

In partial answer to this question, Table 5-3 summarizes the potential benefits of each action under both full and constrained implementation scenarios. It is tempting to sort the actions in Table 5-3 by potential benefit with constrained implementation and view the sorted list as a prioritized list of management actions, with the actions at the top being those predicted to have the greatest benefits.

However, Table 5-3 is misleading as a tool for guiding recovery actions because the potential benefit scores it uses do not accurately account for the magnitude of impact of an action—in other words, the number of fish that could be affected by the action. For example, a given management action could be fully implemented yet result in the survival of only hundreds of additional juvenile salmonids because the threat and limiting factors that the action addresses are relatively minor. Implementation of another action could be constrained, but the action could result in many thousands of additional juveniles surviving because the threat and limiting factors the action addresses are so great.

This consideration of magnitude of impact is important and calls for development of a second analysis of potential benefits of management actions: survival improvement targets, which are presented in the next section of this document.

TABLE 5-3
Summary of Constraints to Implementation of Management Actions

Number	Action Description	Benefit with Full Implementation of Action[1]	Benefit with Constrained Implementation of Action[2]
CRE-01	Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.	4	3
CRE-02	Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.	4	2
CRE-03	Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.	2	1
CRE-04	Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to improve access to habitats and provide better transport of sediments in the estuary, plume, and littoral cell.	5	3
CRE-05	Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.	3	2
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	4	3

CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	2	1
CRE-08	Remove pile dikes that have low navigational value but high impact on estuary circulation or juvenile predation effects.	3	2
CRE-09	Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.	5	3
CRE-10	Breach or lower dikes and levees to improve access to off-channel habitats.	5	2
CRE-11	Reduce the square footage of over-water structures in the estuary.	3	1
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	3	1
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.	2	2
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	3	2
CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.	2	1
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	4	3
CRE-17	Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	4	2
CRE-18	Reduce the abundance of shad entering the estuary.	2	1
CRE-19	Prevent new introductions of invertebrates and reduce the effects of existing infestations.	2	1
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.	3	2
CRE-21	Identify and reduce industrial, commercial, and public sources of pollutants.	4	3
CRE-22	Monitor the estuary for contaminants and/or restore contaminated sites.	4	3
CRE-23	Implement stormwater best management practices in cities and towns.	2	1

[1]Estimate of potential benefit if action is fully implemented.
1 = very low benefits.
5 = very high benefits.

[2]Estimate of potential benefit if implementation is constrained.
1 = very low benefits.
5 = very high benefits.

Evaluation of Management Actions: Survival Improvement Targets

The Columbia River estuary and plume are only two of many ecosystems that salmonids travel in their complex and lengthy journey from headwaters to ocean and back again. Mortality occurs at every stage of this journey. Each year, NOAA Fisheries scientists estimate the number of juvenile salmonids that enter the estuary from upstream of Bonneville Dam and from estuary tributaries. For 2006, NOAA Fisheries scientists estimate that about 168 million juvenile salmonids (both wild and hatchery) will enter the estuary (Ferguson 2006b). To put this number in context, it is estimated that each year approximately 200 million juveniles are planted or emerge from gravel in the tributaries. This means that upstream mortality is about 20 percent of all juvenile salmonids produced in the basin. Some years later, the surviving fish return to the estuary in varying numbers, with the average return in the last 10 years being approximately 1.7 million fish. In other words, less than 1 percent of the juveniles originating in the tributaries are returning as adults, including both hatchery and wild fish.

How much juvenile mortality is occurring in the estuary and plume? The answer to this question is fundamental to developing an understanding of the role the estuary will play in the recovery of salmonid populations basinwide. The answer also is critical in evaluating the benefits and costs of potential management actions because it helps establish the level of effort needed to offset threats to salmonids in the estuary. Unfortunately, determining how much juvenile mortality is occurring in the estuary and plume is challenging for scientists. Counting juveniles in the Columbia River estuary and plume is problematic because available tracking device technologies are limited, and it is difficult to monitor juveniles—which tend to move in and out of saltwater—in large, high-energy sites such as the mouth of the Columbia River.

However, some efforts have been made to separate mortality that occurs in the estuary and plume from mortality that occurs in the ocean. One such effort has been the underlying assumptions in the Ecosystem Diagnosis and Treatment (EDT) model, which is used extensively throughout the Columbia River basin. EDT assumes juvenile mortality rates in the estuary of between 18 and 58 percent, depending on the salmonid species and the amount of time juveniles spend in the estuary (Lower Columbia Fish Recovery Board 2004).

In addition, new research is currently under way by NOAA Fisheries, the U.S. Army Corps of Engineers, and Battelle Laboratories to estimate the survival rate of juvenile salmonids in the lower Columbia River. This research involves new technologies for miniaturizing acoustic tags to a size capable of tracking yearling and subyearling juveniles. Current technology developed for the project allows for the tracking of subyearlings of sizes down to approximately 90 mm. Results for the first year (2005) have not been formally released; however, preliminary data indicate an approximate range of survival of 65 to 75 percent for subyearlings and yearlings during their residency in the estuary (Ferguson 2006a). It is probable that actual survival rates are lower than these preliminary estimates suggest because the research did not address mortality among juveniles smaller than 90 mm or mortality occurring in the plume and nearshore.

Some specific estimates of salmonid mortality are known in the estuary; they include estimates for double-crested cormorants and Caspian terns. For other threats to salmonids, such as toxic contamination, ship wake stranding, and pinniped predation, information on mortality in the estuary is incomplete or relatively new in the literature. Still other threats, especially threats related to the food web, are poorly understood and have no mortality estimates associated with them, although in some cases the change in conditions from the historical template to the present has been well documented.

An important goal of this estuary recovery plan module is to estimate the potential benefits—in terms of increased survival of salmonids in the estuary—that could result from the implementation of different management actions. To accomplish this goal, the estuary recovery plan module uses what is known about limiting factors, threats, and constraints to implementation of management actions to assign benefits that could possibly result from different actions.

If scientific understanding of the relationships between ecological conditions and biological responses in estuarine systems were robust, it would be attractive to assign specific mortality rates to each of the factors limiting salmonids' biological performance in the Columbia River estuary. Then one could follow a deterministic logic path that associates mortality rates with specific threats, relates the mortality rates to management actions, and ultimately arrives at an estimate of the survival improvement that would be likely to result from each action. This is not possible at this time, and it will likely not be possible until there have been significant advances in scientific understanding of the complex estuarine environment.

To compensate for the lack of comprehensive information on mortality in the estuary, this recovery plan module establishes targets for improved survival of wild salmonids rearing and migrating in the estuary and plume. These survival targets are intended to serve as a planning tool useful in characterizing the potential results of actions and describing the level of effort needed to recover salmonids.

The primary purpose of the survival improvement targets is to help compare the potential benefits of different management actions, particularly actions that partially address major limiting factors versus actions that fully address minor limiting factors. Assigning survival improvement targets to management actions is necessary because most other evaluation techniques (such as high, medium, and low type ratings) lack the specificity to indicate that, in some cases, even constrained implementation of an action that addresses a very important limiting factor could result in large survival improvements. However, it should be noted that the usefulness of assigning survival improvement targets is limited by the lack of conclusive field data on the various mortalities that salmonids experience while rearing in or traversing the habitats in the estuary and plume.

The survival improvement targets in this chapter were based on an estimate of the number of wild, ESA-listed ocean- and stream-type juvenile salmonids entering the estuary. The total number of wild, ESA-listed juvenile salmonids estimated to enter the estuary in 2006 is approximately 39 million (Ferguson 2006b).[1] Of these, approximately 25 million are ocean type and 14 million are stream type.

To establish survival improvement targets, some assumptions were made about the overall mortality to juvenile salmonids occurring during estuary and plume residency. Ocean-type

[1] Approximately 98.9 million ESA-listed juveniles (wild and hatchery) are estimated to enter the estuary in 2006. This estuary recovery plan module uses only the wild fraction of these ESA-listed fish.

juveniles were assumed to have an overall mortality rate of 50 percent during their estuary residency; this includes the 35 percent mortality suggested by the unpublished micro-acoustic tagging research (Ferguson 2006a), plus an additional 15 percent to account for juveniles too small to be tracked. Stream-type juveniles were assumed to have an overall mortality rate of 40 percent during estuary and plume residency. This rate was based on the 25 percent mortality found in the micro-acoustic tagging research (Ferguson 2006a), plus an additional 15 percent to account for mortality occurring in the plume, which was not part of study. These assumptions about estuary mortality are not scientifically justifiable; rather, they are estimates used for the purposes of the survival improvement target exercise only.

Table 5-4 shows the number of wild, ESA-listed ocean- and stream-type juveniles thought to be entering the lower Columbia estuary and plume, their estimated mortality and survival rates based on the assumptions above, and the number of juveniles estimated to survive their journey through the estuary and plume—again, based on the assumptions above.

TABLE 5-4
Estimated Mortality Rates, Survival Rates, and Survival Improvement Targets for Wild, ESA-Listed Juveniles

Type	Juveniles Entering Estuary*	Assumed Mortality Rate	Assumed Survival Rate	Estimated Number of Juveniles Exiting Estuary and Plume*	Survival Improvement Target (20 percent)**
Ocean Type	25 million	50%	50%	12.5 million	2.5 million
Stream Type	14 million	40%	60%	8.4 million	1.68 million

* = Wild, ESA-listed juveniles.

** = Twenty percent of the estimated number of juveniles exiting the estuary and plume.

Table 5-4 also presents the survival improvement targets for ocean- and stream-type salmonids in the estuary and plume. These are administrative targets equal to 20 percent of the number of wild, ESA-listed juveniles exiting the estuary and plume, with 20 percent representing a hypothetical level of improvement that might be realized through the implementation of the management actions, assuming that constraints to implementation can be overcome and that threats and limiting factors can effectively be reduced.

The usefulness of the 20 percent target lies not in the 20 percent number itself, but in the distribution of the targets (2.5 million ocean-type juveniles and 1.68 million stream-type juveniles) across the various management actions, as a way of characterizing where survival improvements would need to be realized given the various constraints to action implementation.[2] Table 5-5 shows this allocation of survival improvement targets to the 22 management actions, based on literature sources that identify limiting factors, threats, and management actions. (More information about how survival improvement targets were allocated to the different actions is presented in Appendix B.) The value of this exercise should be viewed within the limitations of the assumptions and estimates described in this section of the estuary recovery plan module.

[2] Although for the purposes of this analysis 20 percent is considered a hypothetical number, it is a plausible number. The 20 percent figure is based on overall estimates of juvenile mortality in the estuary, known mortality that can be attributed to specific threats, and professional judgment regarding the efficacy of the different management actions and the likelihood that constraints to their implementation can be overcome.

Although the accuracy of the numbers in Table 5-5 is uncertain, establishing survival improvement targets complements the analysis summarized in Table 5-3. In addition, the approach illustrates how a small increment of implementation of a far-reaching action could offer significantly more potential for recovery than full implementation of an action that is more limited in scope. Comparison of Tables 5-3 and 5-5 and the cost estimates that are developed in the next section form the basis for prioritization of actions in Chapter 7, "Perspectives on Implementation."

While the survival improvement targets in Table 5-5 only estimate the actual survival potential that might be realized by implementing management actions, the targets do provide a useful way of showing the potential magnitude of juvenile survival at the action scale relative to other actions. In cases where there is good scientific literature that supports survival estimates, as with terns and cormorants, that information has been used. In other cases, such as reservoir heating, an estimate was made by PC Trask & Associates based on literature discussion of related limiting factors and threats. These numbers should be viewed as a product of a planning exercise, not a representation of deterministically based estimates.

The purpose of the analysis reflected in Table 5-5 is to help characterize where survival improvements would need to be realized given the various constraints to action implementation. This is only one scenario; however, given the constraints on all the management actions, it would be difficult to meet the survival improvement targets without the improvements associated with those actions most likely to have significant benefits, such as adjusting flows, breaching or lowering dikes and levees, and, for stream types, reducing predation by cormorants and Caspian terns.

Evaluation of Management Actions: Costs and Schedule

Implementing recovery actions in the estuary will be expensive and require a long-term commitment by many entities. In Tables 5-2 and 5-5, two approaches were used to portray the potential survival improvements associated with implementing actions. In this section, each action is broken down into one or more projects that can be considered elements of that action. Each project has a corresponding unit and cost, and the project costs are summed to produce a total cost.

The costs identified in this section do not represent a detailed economic analysis; in fact, they are not economic costs and have not been discounted across time. Instead, the cost estimates are in constant dollars over a 25-year period. For many projects, the estimates are general because of the speculative nature of the level of effort that will be applied to implement them. Also, this cost estimate attempts to establish a reasonable cost for recovery—it is not a detailed "wish list" of projects that are waiting to be completed. This point is important in the estuary because many of the actions and their component projects do not lend themselves to the type of discrete restoration projects that might occur in a small tributary, like adding large woody debris. In the future, as restoration and protection actions in the estuary occur, this more detailed level of cost estimates may be possible.

TABLE 5-5
Survival Improvement Targets Allocated to Management Actions[1]

Number	Action Description	Survival Improvement Target[1] with Constrained Implementation (numbers of wild, ESA-listed fish)			
		Ocean Type[1]	% of Total Improvement Target	Stream Type[1]	% of Total Improvement Target
CRE-01	Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.	150,000	6%	100,000	6%
CRE-02	Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.	140,000	6%	50,000	3%
CRE-03	Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.	50,000	2%	20,000	1%
CRE-04	Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to improve access to habitats and provide better transport of sediments an the estuary, plume, and littoral cell.	350,000	14%	250,000	14%
CRE-05	Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.	6,000	<1%	5,000	<1%
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	20,000	<1%	12,000	<1%
CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	10,000	<1%	1,000	<1%
CRE-08	Remove pile dikes that have low navigational value but high impact on estuary circulation or juvenile predation effects.	100,000	4%	35,000	2%
CRE-09	Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.	350,000	13%	80,000	5%
CRE-10	Breach or lower dikes and levees to improve access to off-channel habitats.	400,000	15%	100,000	6%

CRE-11	Reduce the square footage of over-water structures in the estuary.	50,000	2%	4,000	<1%
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	60,000	3%	1,000	<1%
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.	4,000	<1%	3,000	<1%
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	500[2]	N/A	4,500[2]	N/A
CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.	50,000	2%	15,000	<1%
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	2,000	<1%	450,000	27%
CRE-17	Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.	2,000	<1%	350,000	21%
CRE-18	Reduce the abundance of shad entering the estuary.	6,000	<1%	2,000	<1%
CRE-19	Prevent new introductions of invertebrates and reduce the effects of existing infestations.	10,000	<1%	2,000	<1%
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.	40,000	2%	18,000	<1%
CRE-21	Identify and reduce industrial, commercial, and public sources of pollutants.	300,000	11%	80,000	5%
CRE-22	Monitor the estuary for contaminants and/or restore contaminated sites.	350,000	13%	90,000	5%
CRE-23	Implement stormwater best management practices in cities and towns.	50,000	2%	12,000	<1%
	Total	2.5 million		1.68 million	

[1] Appendix B presents more information on how survival improvement targets were developed.

[2] CRE-14 relates only to adult salmonids; the survival numbers in Table 5-5 for CRE-14 are not included in the 20 percent survival improvement targets for juvenile salmonids.

In most cases, project costs are direct costs, meaning out-of-pocket costs that a public or private interest would pay to initiate and complete the action. A few actions include indirect costs, meaning the costs associated with foregone economic opportunities or costs that ripple out to the local or regional economy. Finally, action implementation costs should be viewed from a level-of-effort perspective. In most cases, the degree to which actions can be implemented is speculative. This is true for a variety of reasons, but economic, social, political, scientific, and public safety constraints often limit an action's potential for implementation.

Table 5-6 establishes costs for each of the 23 actions in the estuary recovery plan module. It may be determined that not all actions or their corresponding projects should be implemented. On the other hand, new actions or projects may emerge. Most importantly, the development of costs for this suite of actions and projects is an optimistic view of the potential to overcome constraints. This is partly because constraints often represent past societal choices that are virtually impossible to reverse. The costs identified in Table 5-6 were developed by PC Trask & Associates with input from jurisdictions and agencies. It is anticipated that these estimates will be refined as larger societal decisions are made.

Each action in Table 5-6 includes a proposed schedule for implementation. The schedule is designed to place projects in a logical order and spread costs over a long period of time when possible. Costs are identified over a 25-year span, with some projects being implemented once over a relatively short period and others continuing over the entire 25 years.

Other elements contained in Table 5-6 include the association of actions to specific geographical reaches, key assumptions about actions, and notes that help explain how costs were developed. The relationship of actions to the eight geographic reaches and the plume helps to define the breadth of the action and may also indicate which jurisdictions may implement actions in the future. Key assumptions relate primarily to implementation and provide insight into the level of effort reflected in the action costs. Notes are specific information that helps clarify a particular unit or cost.

TABLE 5-6
Estimated Cost and Schedule

Management Action CRE-1:

Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.

Project	Unit	Cost	Schedule
1. Educate landowners about the ecosystem benefits of intact riparian areas and the costs of degraded riparian areas.	25 years @ $250,000/year	$6.25 million	2008 - 2033
2. Encourage and provide incentives for local, state, and federal regulatory entities to maintain, improve (where needed), and enforce consistent riparian area protections throughout the lower Columbia region.	8 years @ $200,000/year	$1.6 million	2008 - 2016
3. Actively purchase riparian areas in urban and rural settings that (1) cannot be effectively protected through regulation, (2) are intact, or (3) are degraded but have good restoration potential.	Rural: 1,500 acres at $5,000/acre[1] Urban: 75 acres at $100,000/acre	$15 million	2007 - 2031
4. Restore and maintain ecological benefits in riparian areas; this includes managing vegetation on dikes and levees to enhance ecological function.	20 miles @ $500,000/mile	$ 10 million	2006 - 2031

Total costs: $32.85 million

Geographical extent: Reaches A, B, C and H.

Key assumptions: (1) New homes, businesses, and industry will increase with population growth in the basin. (2) Some intact riparian areas are not adequately protected. (3) Protecting intact riparian areas would be cheaper than restoring degraded areas. (4) Some degraded riparian areas could be restored and gain ecological function, with associated downstream benefits. (5) Comprehensive protection and restoration of riparian habitats would occur concurrently with population growth, which will continue at a high rate.

Notes:
[1] Acreage amounts are 25-year targets that depend on willing sellers and funding.

Management Action CRE-2:

Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.

Project	Unit	Cost	Schedule
1. Conduct a reservoir heating study to determine the extent of the issue and identify hydrosystem operational changes that would reduce effects and/or mitigate downstream temperature issues.	1 study	$2.5 million	2007 - 2013
2. Implement hydrosystem operational changes to reduce temperature effects; if no change is possible, mitigate effects through restoration of tributary riparian areas.	25 years @ $900,000/year[1]	$22.5 million	2010 - 2032

Total costs: $25 million

Geographical extent: All reaches (A-H), including the plume and nearshore.

Key assumption: (1) Either there is potential to alter management practices in the hydrosystem to reduce flow temperatures or a commensurate level of mitigation in tributaries would reduce temperatures in the estuary. (2) If temperatures continue to increase above 19° C, the estuary could become completely lethal for salmonids and other native species.

Notes:
[1] Assumes that some level of improvement is possible, but that the level of possible improvement is likely to be minor because of complexities of the hydrosystem; assumes that mitigation will be needed to offset temperature increases.

Management Action CRE-3:

Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.

Project	Unit	Cost	Schedule
1. Establish a forum to explore options and develop policy recommendations on instream flows.	5 years @ $1 million/year[1]	$5 million	2007 - 2015
2. Implement instream flow regulations in accordance with the policy recommendations in Project No. 1.	5 years @ $1 million/year[2]	$5 million	2015 - 2023

Total costs: $10 million

Geographical extent: All reaches, including the plume and nearshore.

Key assumptions: (1) Demand for water for human use will grow as the human population in the basin increases. (2) Additional legal instream flows in the Columbia River mainstem and tributaries could be established through the efforts of affected parties basinwide. (3) Establishing a legal instream flow would protect flows entering the estuary in the future. (4) An instream flow law would help develop additional water conservation efforts and guide land use development in concert with water availability.

Notes:

[1]Costs are associated with developing the planning capacity (i.e., staff, office, technical support) to support the basinwide entity.

[2]Costs are associated with staffing the law-making activities needed to implement basinwide instream flow.

Management Action CRE-4:

Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to improve access to habitats and provide better transport of sediments in the estuary, plume, and littoral cell.

Project	Unit	Cost	Schedule
1. Conduct a flood study to determine the risks and feasibility of returning the estuary hydrograph to more normative flows.	2 years @ $500,000/year	$1 million	2009 - 2010
2. Conduct a study to determine the habitat effects of increasing the magnitude and frequency of flows (i.e., how much access of river to off-channel habitats would increase).	3 years @ $500,000/year	$1.5 million	2009 - 2011
3. Conduct additional studies to determine the extent of other constraints, including international treaties, systemwide fish management objectives, and power management.	4 years @ $500,000/year	$2 million	2010 - 2014
4. Make policy recommendations to action agencies on flow, taking into consideration beneficial estuary flows, flood management, power generation, irrigation, water supply, fish management, and other interests.	25 years @ $100,000/year	$2.5 million	2010 - 2035
5. Implement modified estuary flow regime annually in concert with other interests, including hydroelectric, flood control, and water withdrawals.	25 years @ $2 million/year[1]	$50 million	2011 - 2036

Total costs: $57 million

Geographical extent: All reaches (A-H), the plume, and the Columbia River littoral cell.

Key assumptions: (1) Even incremental changes in the magnitude and frequency of flows would improve salmonid habitat opportunity and food inputs, which would have benefits throughout the ecosystem. (2) Studies of flood risk and the effect of flow changes on estuarine habitat would provide data useful in modifying hydrosystem operations to benefit salmonids. (3) Studies of constraints to implementation would identify some obstacles that could be overcome. (4) Small to moderate changes in the magnitude, frequency, and timing of flows would improve sediment transport-related habitat opportunity in the estuary. (5) Increased spring freshets would yield greater sediment transport-related benefits than would other flow modifications.

Notes:

[1] Assumes a $2 million per year cost of decreased hydrosystem generation revenues to compensate for hydrosystem impacts to fish and wildlife; also assumes that flood risk associated with beneficial estuary flows does not increase significantly.

Management Action CRE-5:

Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.

Project	Unit	Cost	Schedule
1. Identify the effects of reservoir sediment entrapment on economic and ecological processes; this includes effects on ship channels, turning basins, port access, jetty activities, littoral cell erosion and accretion, and habitat availability.	1 study	$2 million	2008 - 2011
2. Establish a forum to develop a regionwide sediment plan for the estuary and littoral cell.	10 years at $100,000/year	$1 million	2006 – 2031
3. Implement projects recommended in the plan to mitigate the effects of sediment entrapment.	5 projects @ $1 million/project	$5 million	2010 - 2020

Total costs: $7 million

Geographical extent: All reaches (A-H), including the plume and littoral cell.

Key assumptions: (1) Sediment entrapment in reservoirs will continue. (2) Sediment entrapment has negative effects, both ecologically and economically. (3) The extent of these effects warrants exploration and implementation of potential mitigation measures. (4) Studying potential mitigation measures would identify some actions that would be effective and could be implemented.

Management Action CRE-6:

Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.

Project	Unit	Cost	Schedule
1. Establish a forum to develop a regionwide sediment plan for the estuary and littoral cell.	See CRE-5.	See CRE-5.	See CRE-5.
2. Identify and implement demonstration projects designed to assess ecosystem beneficial uses of dredged materials.	10 projects @ $100,000/project	$1 million	2006 - 2012
3. Dispose of dredged materials using techniques identified through the demonstration projects and regionwide planning.	10 years @ $500,000/year[1]	$5 million	2008 - 2033

Total costs: $7 million

Geographical extent: Reaches A, B, C and the plume and nearshore.

Key assumptions: (1) Dredging activities will continue or increase over time. (2) Opportunities to beneficially use dredged materials for habitat can be identified. (3) Beneficial use of dredged material would have a positive effect on sediment transport and habitat-forming processes in the estuary, plume, and littoral cell.

Notes:

[1]Unit cost is funding to pay for activities beyond the minimum required by law, to achieve regional-scale ecosystem benefits.

Management Action CRE-7:

Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.

Project	Unit	Cost	Schedule
1. Identify and evaluate dredge operation techniques designed to reduce entrainment and other habitat effects.	1 project	$500,000	2008 - 2010
2. Initiate demonstration projects designed to test and evaluate dredge operations.	5 projects @ $200,000/project	$1 million	2009 - 2012
3. Implement best management techniques.	10 years @ $250,000/year[1]	$2.5 million	2011 - 2036

Total costs: $4 million

Geographical extent: Reaches B, C, D, E and F.

Key assumptions: (1) Improved best management practices can be identified that would help reduce the impact of dredging. (2) Mitigation activities would help offset changes to the estuary caused by dredging.

Notes:
[1]This is an estimate of the incremental cost above permitted dredge activities. Cost may vary significantly depending on site-specific conditions.

Management Action CRE-8:

Remove pile dikes that have low navigational value but high impact on estuary circulation or juvenile predation effects.

Project	Unit	Cost	Schedule
1. Inventory, assess, and evaluate in-channel pile dikes for their economic value and their impact on the estuary ecosystem; develop criteria for establishing project priority.	1 plan	$200,000	2007 - 2009
2. Remove priority pile dikes.	10 sets[1] @ $250,000/set	$2.5 million	2008 - 2033
3. Monitor the physical and biological effects of pile dike removal.	10 years @ $100,000/year	$1 million	2010 - 2020

Total costs: $3.7 million

Geographical extent: Reaches A, B, C, D, E, F, G and H.

Key assumption: (1) Many pile dikes and navigational structures could be removed without compromising the shipping channel or protection of property. (2) Over time, the removal of superfluous pile dikes would improve conditions for salmonids and the ecosystem.

Notes:
[1]A set is a logical grouping of a large number of priority pile dikes targeted for removal.

Management Action CRE-9:

Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.

Project	Unit	Cost	Schedule
1. Educate landowners about the ecosystem benefits of protecting and stewarding intact off-channel areas and the costs of restoring degraded areas.	15 years @ $250,000/year	$3.75 million	2007 - 2032
2. Encourage and provide incentives for local, state, and federal regulatory entities to maintain, improve (where needed), and enforce consistent riparian area protections throughout the lower Columbia region.	10 years @ $1 million/year	$10 million	2007 - 2032
3. Actively purchase off-channel habitats in urban and rural settings that (1) cannot be effectively protected through regulation, (2) are degraded but have good restoration potential, or (3) are highly degraded but could benefit from long-term restoration solutions.[1]	Rural: 3,000 acres at $5,000/acre Urban: 150 acres at $100,000/acre	$30 million	2007 - 2031

Total costs: $43.75 million

Geographical extent: Reaches A, B, and C.

Key assumptions: (1) Protection opportunities can be increased over the next decade through public awareness, education, regulatory, and acquisition programs. (2) Protection of off-channel habitats is less expensive than restoration. (3) High-quality off-channel habitats offer benefits to salmonids that cannot be provided in other ways. (4) Protection will be needed to off-set increasing threats resulting from human population increases in the estuary and basin.

Notes:
[1]Assumes purchases are made over a 25-year period with willing sellers.

Management Action CRE-10:

Breach or lower dikes and levees to improve access to off-channel habitats.

Project	Unit	Cost	Schedule
1. Breach or lower the elevation of dikes and levees; create and/or restore tidal marshes, shallow-water habitats, and tide channels.	3,000 acres[1] @ $10,000/acre	$30 million	2006 - 2031
2. Remove tide gates to improve the hydrology between wetlands and the channel and to provide juveniles with physical access to off-channel habitat; use a habitat connectivity index to prioritize projects.	1,500 acres[1] @ $10,000/acre	$15 million	2006 - 2031
3. Upgrade tide gates where (1) no other options exist, (2) upgraded structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.	500 acres[1] @ $10,000/acre	$5 million	2006 - 2031

Total costs: $50 million

Geographical extent: Reaches A, B, C, E, F, and G.

Key assumptions: (1) Additional opportunities to restore off-channel habitats can be developed through long-term outreach and improved landowner relationships. (2) Restoration of sites, including elevation restoration, would yield broad-scale ecosystem benefits over time. (3) A habitat connectivity index would help target efforts toward the projects that would provide the greatest benefits. (4) Restoration of highly degraded sites may be necessary to yield long-term benefits.

Notes:

[1]Acreage equals amount of affected area. Costs include those associated with protecting other land uses from renovated hydrology (i.e., moving dikes and levees).

Management Action CRE 11:

Reduce the square footage of over-water structures in the estuary.

Project	Unit	Cost	Schedule
1. Inventory over-water structures and develop a GIS layer with detailed metadata files.	2 projects @ $150,000/project	$300,000	2007 - 2009
2. Initiate a planning process to evaluate existing and new over-water structures for their economic, ecological, and recreational value.	2 phases[1] @ $100,000/phase	$200,000	2009 - 2013
3. Remove over-water structures that no longer serve a functional use and/or reduce the footprint of viable structures when appropriate.	10 projects @ $500,000/project[2]	$5 million	2012 - 2037
4. Establish criteria for new permit applications to consider the cumulative impacts of over-water structures.	1 project	$300,000	2008 - 2010

Total costs: $5.8 million

Geographical extent: Reaches D and G.

Key assumptions: (1) Over-water structures pose some threat to salmonids. (2) A fair number of over-water structures are no longer in use or have relatively minor value to owners. (3) An inventory of over-water structures would aid in assessing individual structures' economic, ecological, and recreational value.

Notes:
[1]The first phase is technical and the second phase is policy.
[2]A project is defined as a set of structures that have been identified for removal; cost is level of effort.

Management Action CRE-12:

Reduce the effects of vessel wake stranding in the estuary.

Project	Unit	Cost	Schedule
1. Use existing research results documenting stranding by ship wakes to estimate juvenile mortality throughout the estuary. Modeling could use newly emerging Light Detection and Ranging (LIDAR) satellite imagery to conduct analyses.	1 study	$500,000	2007
2. Analyze factors contributing to ship wake stranding to determine potential approaches to reducing mortality in locations where juveniles are most vulnerable. Design and implement demonstration projects and monitor their results.	1 three-phase study @ $500,000/phase	$1.5 million	2007 - 2010
3. Implement projects identified in Project No. 2 that are likely to result in the reduction of ship wake stranding events.	10 projects @ $1.5 million/project[1]	$15 million	2011 - 2026

Total costs: $17 million

Geographical extent: Reaches C, D, E and F.

Key assumptions: (1) Vessel wake stranding is a significant issue for ocean- and stream-type salmonids employing the fry life history strategy in the estuary.

Notes:
[1] This is a level-of-effort cost approach that will require information generated in Projects No. 1 and 2.

Management Action CRE-13:

Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.

Project	Unit	Cost	Schedule
1. Monitor the abundance levels of pikeminnow, smallmouth bass, walleye, and channel catfish.	5 monitoring events @ $10,000/event (every 5 years)	$50,000	2006 - 2031
2. Implement actions as necessary to prevent population growth (i.e., modify habitat); continue the northern pikeminnow bounty program.	5 projects @ $200,000/project[1]	$1 million	2006 - 2031

Total costs: $1.050 million

Geographical extent: Reaches D, E, F, G and H.

Key assumption: Management techniques would maintain populations at levels that would maintain or reduce predation impacts to salmonids.

Notes:
[1] It is unknown whether projects will be needed to manage warm-water fish. In some cases, there may be warm-water habits close to juvenile habitat, in which case site-specific action would be required.

Management Action CRE-14:

Identify and implement actions to reduce salmonid predation by pinnipeds.

Project	Unit	Cost	Schedule
1. Expand federal and state activities at Bonneville Dam to test non-lethal and potentially lethal methods of reducing pinniped populations throughout the estuary. This includes efforts to manage pinnipeds through the Marine Mammal Protection Act.	3 projects @ $500,000/project	$1.5 million	2007 - 2011
2. Implement actions likely to reduce pinniped predation on adult salmonids.	25 years @ $500,000/year[1]	$12.5 million	2007 - 2032

Total costs: $12.65 million

Geographical extent: All reaches (especially H).

Key assumptions: (1) Mortality from pinnipeds may be a larger source of salmonid mortality than previously understood. (2) Further study would clarify the impact of pinniped predation on salmonids. (3) Mortality from pinniped predation could be reduced through non-lethal and lethal methods. (4) The Marine Mammal Protection Act could be modified over time to allow more tools for managing pinnipeds in the estuary.

Notes:
[1] Units are years; given legal constraints, it is likely that ongoing efforts to prevent predation will continue over the next 25 years.

Management Action CRE-15:

Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.

Project	Unit	Cost	Schedule
1. Increase public awareness of exotic plant species and proper stewardship techniques.[1]	15 years @ $300,000/year	$4.5 million	2008 - 2023
2. Inventory exotic plant species infestations and develop a GIS layer with detailed metadata files.	5 phases @ $250,000/phase	$1.25 million	2007 - 2012
3. Implement projects to address infestations on public and private lands.	15 years @ $1 million/year	$15 million	2008 - 2033
4. Monitor infestation sites.	20 years @ $25,000/year	$500,000	2010 - 2035

Total costs: $21.25 million

Geographical extent: All reaches (A-H).

Key assumptions: (1) Aquatic noxious weeds have a negative effect on the estuary ecosystem and affect juvenile salmonids by altering habitat and causing food webs to deteriorate. (2) Additional information is needed on the location, extent, and type of infestations and their effects on the estuary ecosystem. (3) Because introductions of noxious weeds can permanently alter the estuary ecosystem, prevention activities are crucial. (4) Education, outreach, and monitoring would help prevent further introductions of exotic plants.

Notes:

[1]This project is recommended for upstream mainstem and tributaries, but the costs presented here are for activities in the estuary only. Many exotic plants have established themselves upstream and represent a constant downstream threat to the estuary.

Management Action CRE-16:

Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.

Project	Unit	Cost	Schedule
1. Enhance or create tern nesting habitat at alternative sites in Washington, Oregon, and California.	3 sites @ $1 million/site	$3 million	2008 - 2012
2. Reduce tern nesting habitat on East Sand Island to 1 to 1.5 acres.	1 project @ $2.5 million/project	$2.5 million	2007 - 2010
3. Monitor the regional tern population.	25 years @ $100,000/year	$2.5 million	2010 - 2035

Total costs: $8 million

Geographical extent: Reaches A and B.

Key assumption: Ongoing and new management actions directed to Caspian tern nesting habitat would continue to reduce salmonid mortality from tern predation.

Management Action CRE-17:

Implement projects to reduce double-crested cormorant habitats and encourage dispersal to other locations.

Project	Unit	Cost	Schedule
1. Identify, assess, and evaluate methods of reducing double-crested cormorant abundance numbers.	1 multiphase study	$2.5 million	2007 - 2011
2. Implement demonstration projects resulting from Project No. 1 (i.e., decoys and audio playback methods).	5 pilot projects @ $500,000/project	$2.5 million	2010 - 2015
3. Implement projects resulting in reduced predation by cormorants.[1]	10 years @ $500,000/year	$5 million	2013 - 2023

Total costs: $10 million

Geographical extent: Reaches A and B.

Notes:
[1]This is a level-of-effort cost estimate; efforts to manage cormorants in the estuary are significantly lagging Caspian tern management efforts.

Management Action CRE-18:

Reduce the abundance of shad entering the estuary.

Project	Unit	Cost	Schedule
1. Initiate a planning process to organize technical information about shad and identify potential control methods.	2 phases @ $250,000/phases	$500,000	2007 - 2011
2. Implement demonstration projects to evaluate effective management methods.	4 projects @ $500,000/project	$2 million	2008 - 2015
3. Implement shad population management techniques.[1]	10 years @ $25,000/year	$2.5 million	2010 - 2015
4. Monitor and evaluate management techniques.	10 years @ $50,000/year	$500,000	2011 - 2021

Total costs: $5.5 million

Geographical extent: All reaches (A-H).

Key assumptions: (1) Shad have negative affects on salmonids in the estuary. (2) Additional research would shed light on how shad affect salmonids and suggest new management techniques. (3) New management techniques would be unlikely to cause significant change.

Notes:
[1]This is a level-of-effort cost estimate; currently there are no plans to manage shad abundance levels in the Columbia River.

Management Action CRE-19:

Prevent new introductions of invertebrates and reduce the effects of existing infestations.

Project	Unit	Cost	Schedule
1. Establish a forum to (1) assemble existing technical information on introduced invertebrates in the estuary, and (2) develop a plan for managing existing infestations.	2 phases @ $250,000/phase	$500,000	2007 - 2010
2. Implement recommendations from the plan for managing existing infestations (Project No. 1, above).[1]	5 projects @ $500,000/project	$2.5 million	2008 - 2013

Total costs: $3 million

Geographical extent: All reaches (A-H).

Key assumptions: (1) Ship ballast practices could be improved to help prevent further degradation of the estuary ecosystem. (2) Additional research would help scientists understand the effects of exotic invertebrates on the ecosystem. (3) Because the effects of exotic invertebrates on the ecosystem usually cannot be reversed, it is important to prevent introductions when possible.

Notes:
[1]This is a level-of-effort cost estimate.

Management Action CRE-20:

Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.

Project	Unit	Cost	Schedule
1. Increase funding for education and outreach programs targeted to professional and leisure agricultural activities so as to promote reduced use of toxic materials.	10 years @ $700,000/year[1]	$7 million	2008 - 2018

Total costs: $7 million

Geographical extent: All reaches (A-H).

Key assumptions: (1) Some users of pesticides and fertilizers are not adequately informed about best management practices for these toxic contaminants. (2) Additional benefits to salmonids could be realized through continued efforts by farmers, chemical manufacturers, and regulatory programs to reduce impacts from fertilizers and pesticides. (3) Benefits to salmonids would increase over a relatively long period time as agricultural practices improve.

Notes:
[1]Unit cost includes estimates for the estuary and estuary tributaries only; the action recommends similar upstream activities.

Management Action CRE-21:

Identify and reduce industrial, commercial, and public sources of pollutants.

Project	Unit	Cost	Schedule
1. Identify non-permitted point-source pollutant discharge sites and take enforcement action where necessary.	8 years @ $150,000/year	$1.2 million	2007 - 2014
2. Provide cost-share incentives for National Pollution Discharge Elimination System (NPDES) permit holders to upgrade effluent above their permit requirements.	10 years @ $2 million/year	$20 million	2010 - 2020
3. Study and establish threshold treatment standards for pharmaceuticals and other unregulated substance discharges; update existing NPDES permits to reflect the new standards.	5 years @ $2 million/year	$10 million	2007 - 2012
4. Provide grants and low-cost loans to permit holders required to treat effluent to standards established in Project No. 3.	10 years @ $2 million/year	$20 million	2012 - 2017

Total costs: $51.2 million

Geographical extent: Reaches D and G.

Key assumptions: (1) Non-permitted discharges that currently are occurring would be identified and curtailed. (2) Financial incentives or support would motivate NPDES permit holders to raise their effluent treatment levels above permit requirements. (3) Releases of industrial and commercial pollutants into the estuary would be reduced over time.

Management Action CRE-22:

Monitor the estuary for contaminants and/or restore contaminated sites.

Project	Unit	Cost	Schedule
1. Implement contamination monitoring recommendations identified in the *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Pacific Northwest National Laboratory 2006).	TBD	TBD[1]	2006 - 2031
2. Develop criteria and a process for evaluating contaminated sites to establish their restoration potential.	1 phase @ $500,000/phase	$500,000	2007 - 2017
3. Develop an integrated multi-state funding strategy to address contamination cleanup in the estuary from non-identifiable upstream sources.	Out-of-Estuary[2]	n/a	2007 - 2012
4. Restore those contaminated sites that will yield the greatest ecological and economic benefits.	25 years @ $2.7 million/year	$67.5 million	2007 - 2032

Total costs: $68 million

Geographical extent: Reaches A, B, C, D, E, F, G, and H.

Key assumptions: (1) Monitoring will continue to provide vital data needed to understand the toxic contaminant problem and identify potential solutions. (2) Monitoring will identify hot spots of contamination. (3) Contamination sites will be identified for which responsible parties cannot be determined. (4) Additional analysis would identify contamination sites whose restoration would yield significant ecological and economic benefits. (5) Restoration of contaminated sites would benefit salmonids and the ecosystem over time.

Notes:

[1] Monitoring costs to be developed through the estuary/ocean subgroup established in response to the Federal Columbia River Power System (FCRPS) Biological Opinions.

[2] Cost is considered to be outside the purview of estuary-specific projects.

Management Action CRE-23:

Implement stormwater best management practices in cities and towns.

Project	Unit	Cost	Schedule
1. Monitor stormwater outputs to measure treatment compliance with existing local and state regulations throughout the basin.	10 years @ $200,000/year	$2 million	2007 - 2015
2. Establish a fund source for regulatory agencies to use when insufficient resources are available to (1) access best available science, (2) develop standards beyond requirements, or (3) adequately enforce regulations.	4 years @ $2 million/year	$8 million	2007 - 2015

Total costs: $10 million

Geographical extent: Reaches D and G.

Key assumptions: (1) Population growth in the Columbia River basin will continue to influence the hydrology and water quality in the estuary. (2) Stormwater practices could be improved by monitoring and enforcing compliance with existing regulations, making best scientific information available, and developing higher standards. (3) The resulting improvements in hydrology and contaminant exposure in the estuary would occur slowly over time. (4) This action is protective in nature; costs are not associated with retrofitting existing stormwater facilities.

Notes:
This project is recommended for upstream mainstem and tributaries, but the costs presented here are for activities in the estuary only.

Table 5-7 is a summary of costs for the 23 management actions. The total estimated budget for implementation of the actions at this level of effort approaches $500 million over 25 years. This number contrasts with the $1.1 billion estimated to help restore salmon in Puget Sound tributaries over a 10-year period. Other major ecosystem restoration efforts across the United States, including San Francisco Bay, Chesapeake Bay, the Everglades, and the Louisiana Coast, are estimated to cost several billion dollars apiece.

TABLE 5-7
Summary of Costs of Management Actions

Number	Action Description	Cost for Constrained Implementation	%*
CRE-01	Protect intact riparian areas in the estuary and its tributaries and restore riparian areas that are degraded.	$32.85 million	7%
CRE-02	Modify hydrosystem operations to reduce the effects of reservoir surface heating, or conduct mitigation measures.	$25 million	5%
CRE-03	Establish legal instream flows for the estuary that would help prevent further degradation of the ecosystem.	$10 million	2%
CRE-04	Adjust the timing, magnitude and frequency of flows (especially spring freshets) entering the estuary and plume to improve access to habitats and provide better transport of sediments in the estuary, plume, and littoral cell.	$57 million	11%
CRE-05	Study and mitigate the effects of entrapment of sediment in reservoirs, to improve nourishment of the littoral cell.	$7 million	1%
CRE-06	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	$7 million	1%
CRE-07	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	$4 million	1%
CRE-08	Remove pile dikes that have low navigational value but high impact on estuary circulation or juvenile predation effects.	$3.7 million	1%
CRE-09	Protect remaining high-quality off-channel habitat from degradation through education, regulation, and fee simple and less-than-fee acquisition.	$43.75 million	9%
CRE-10	Breach or lower dikes and levees to improve access to off-channel habitats.	$50 million	10%
CRE-11	Reduce the square footage of over-water structures in the estuary.	$5.8 million	1%
CRE-12	Reduce the effects of vessel wake stranding in the estuary.	$17 million	3%
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and channel catfish to prevent increases in abundance.	$1.05 million	0%
CRE-14	Identify and implement actions to reduce salmonid predation by pinnipeds.	$12.65 million	3%

CRE-15	Implement education and monitoring projects and enforce existing laws to reduce the introduction and spread of noxious weeds.	$21.25 million	4%
CRE-16	Implement projects to redistribute part of the Caspian tern colony currently nesting on East Sand Island.	$8 million	2%
CRE-17	Implement projects to reduce double-breasted cormorant habitats and encourage dispersal to other locations.	$10 million	2%
CRE-18	Reduce the abundance of shad entering the estuary.	$5.5 million	1%
CRE-19	Prevent new introductions of invertebrates and reduce the effects of existing infestations.	$3 million	1%
CRE-20	Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic contaminants entering the estuary.	$7 million	1%
CRE-21	Identify and reduce industrial, commercial, and public sources of pollutants.	$51.2 million	10%
CRE-22	Monitor the estuary for contaminants and/or restore contaminated sites.	$68 million	13%
CRE-23	Implement stormwater best management practices in cities and towns.	$10 million	2%
	Total	$460.75 million	

*Column shows the relative percentage of each action to the total cost.

Summary

The estuary and plume ecosystems are especially vulnerable to threats because these ecosystems are affected by factors across a wide geographic range—from upstream to the estuary itself, and even well out in the Pacific Ocean. A set of actions has been identified to help address threats to salmonids in the estuary, plume, and nearshore. Other recovery venues must also address upstream threats to effectively improve degraded habitats in the estuary. It is difficult to characterize these estuary actions in terms of their effectiveness because overall salmonid mortality in the estuary and specific mortality rates related to certain threats are only beginning to be understood. This estuary recovery plan module uses survival improvement targets to help characterize the level of effort required and the costs of that effort.

CHAPTER 6

Monitoring, Research, and Evaluation

Several important monitoring activities are occurring throughout the Columbia River basin that have a direct bearing on the estuary, plume, and nearshore. They include those associated with the following:

- Draft *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006)
- Lower Columbia River Estuary Partnership (1998)
- Recovery plans for salmon species of the Columbia Basin listed under the U.S. Endangered Species Act (National Oceanic and Atmospheric Administration 2005)
- Washington and Oregon salmon recovery programs (Washington Salmon Recovery Funding Board 2002 and Oregon Watershed Enhancement Board 2005)
- Federal Columbia River Power System Biological Opinion implementation (National Oceanic and Atmospheric Administration 2003, Johnson et al. 2004, Upper Columbia Regional Technical Team 2004, and Independent Science Advisory Board and Independent Science Review Panel 2004)
- Northwest Power and Conservation Council's *Columbia River Basin Fish and Wildlife Program* (Northwest Power and Conservation Council 2004)
- Pacific Northwest Aquatic Monitoring Partnership (2005a and 2005b)
- Collaborative Systemwide Monitoring and Evaluation Project (Columbia Basin Fish and Wildlife Authority 2005)

In the development of this estuary recovery plan module, it was recognized that creating a new monitoring plan for the estuary, plume, and nearshore would, at best, only duplicate some of the maturing efforts identified above. In particular, the draft *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006) is recognized as the appropriate monitoring plan to complement the estuary recovery plan module. This monitoring plan is important because it links the estuary module to the 2000 and 2004 *Biological Opinions on Operation of the Federal Columbia River Power System.* Also, the Federal Columbia River Estuary Research, Monitoring, and Evaluation (ERME) Program has a standing estuary/ocean subgroup that continues to refine the monitoring plan; the group's members include the Bonneville Power Administration, the U.S. Army Corps of Engineers, the Lower Columbia River Estuary Partnership, NOAA Fisheries, and the Pacific Northwest National Laboratory. Finally, versions of the ERME Program's monitoring plan were reviewed by the Independent Scientific Review Panel and the Independent Science Advisory Board and other state and tribal fisheries management agencies. This represents important institutional capacity to ensure successful implementation of the monitoring plan over time.

Status and Trends Monitoring

Status and trends monitoring includes the collection of standardized basic information used to monitor broad-scale trends over time in the status of fish populations, conditions in the habitat they use, and other ecosystem factors that affect fish. Status and trends monitoring typically includes the core elements of any monitoring program, such as annual fish numbers and survival rates. This information serves as the basis for evaluating the cumulative effects of suites of management actions on fish, habitat, and the ecosystem.

The overall objective of status and trends monitoring in the ERME Program's monitoring plan is to "measure the status and trends of monitored indicators that are ecologically significant to listed salmonids in the lower river, estuary, plume, and nearshore ocean" (Johnson et al. 2006). The following sub-objectives are from the ERME Program document:

- STM 1: Evaluate the status and trends of stressors for ecosystem controlling factors at an estuary-wide scale.
- STM 2: Evaluate the status and trends of factors controlling ecosystem structures and processes at site and estuary-wide scales.
- STM 3: Evaluate the status and trends of ecosystem structures at site and landscape scales.
- STM 4: Evaluate the status and trends of ecosystem function—juvenile salmonid performance—at the site scale.

Additional information about status and trends monitoring objectives and their relationship to a conceptual model can be found in the May 2006 draft version of the *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006).

Action Effectiveness Research

Action effectiveness research involves project-scale monitoring of local conditions to determine whether implemented actions were effective in creating the desired proximate change. Action effectiveness monitoring typically is used to determine whether project- or program-specific performance goals are met. This type of monitoring also includes post-project monitoring to see whether the actions continue to function as they were designed or intended. In some cases the information needed for action effectiveness research may be provided by status monitoring, but action effectiveness research generally requires focused evaluations of more specific parameters directly associated with actions.

The overall objective of action effectiveness research in the draft *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* is to "use quantitative studies to demonstrate how habitat restoration actions affect factors controlling ecosystem structures and processes at site and landscape scales and produce changes in juvenile salmonid performance" (Johnson et al. 2006). The following sub-objectives are from the ERME Program document:

- AER 1: Measure the effects of individual habitat restoration actions at project sites relative to reference sites and evaluate post-restoration trajectories based on project-specific goals and objectives (effectiveness monitoring).

- AER 2: Estimate the collective effects of habitat conservation and restoration projects in terms of cause-and-effect relationships between ecosystem controlling factors, structures, and processes affecting salmon habitats and performance (validation monitoring).

Additional information about the action effectiveness research objectives and their relationship to a conceptual model can be found in the May 2006 draft version of the *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006).

Uncertainties Research

Uncertainties research consists of scientific investigations of critical assumptions and unknowns that constrain effective recovery plan implementation. Uncertainties include currently unavailable pieces of information required for informed decision making, as well as studies to establish or verify cause-and-effect relationships among fish, limiting factors, and projects or programs meant to protect or enhance fish production or affect limiting factors.

The overall objective of uncertainties research in the draft *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* is to answer the question, "What are the key uncertainties in the state-of-the-science on the estuary that prevent the achievement of habitat, fish, or wildlife performance objectives in the Columbia Basin and how can these be reduced?" (Johnson et al. 2006). The following sub-objectives are from the ERME Program document:

- UR 1: Quantify the ecological importance of the estuary and nearshore ocean in terms of the relationships between salmon population performance and ecosystem structures, ecological processes, life history patterns, and genetic conditions.

  Uncertainties:

  1a: Linkage between habitat conditions and growth and survival of juvenile salmonid fishes in the estuary and ocean.

  1b. Ecosystem controlling factors, structures, and processes of the estuary and ocean that are limiting for the salmon ESUs.

  1c. Survival rates and factors affecting survival in the estuary and plume for the salmon ESUs.

  1d. Effect of timing of ocean entry and, during this period, whether concurrent monitoring of ocean conditions and salmonid migration patterns, growth, and survival can be used to predict inter-annual variations in sizes of runs of returning adult salmonids.

- UR 2: Identify land and water management actions, such as Federal Columbia River Power System (FCRPS) operations, which could improve estuary habitats.

  Uncertainties:

  2a. Effects of hydrograph changes due to the FCRPS on juvenile salmon habitat opportunity, structure, and function.

  2b. The primary driver of the historic estuarine food web.

  2c. The importance of the estuary actions relative to actions in the hydrosystem and tributary habitats.

- UR 3: Prioritize habitats and locations for conservation and restoration in the estuary.

  Uncertainties:

  3a. *The extent of habitat usage by juvenile salmon in the tidal freshwater reach of the estuary (RM 46 to 146).*

  3b. *The spatial and temporal usage of estuary habitats by listed salmonids with various life histories.*

  3c. *The accessibility of habitat to juvenile salmon.*

  3d. *The hydrogeomorphic classification of habitats in the Columbia River estuary.*

- UR 4: Determine the effects of toxics on salmonid performance in the Columbia River estuary.

  Uncertainties:

  4a. *The distribution and concentration of toxics in the Columbia River estuary.*

  4b. *The effect toxics have on salmonid performance.*

Additional information about the uncertainties research objectives and their relationship to a conceptual model can be found in the May 2006 version of the *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006).

Data and Information Management

Data and other information pertinent to the ERME are appropriately collected by many parties for a wide variety of applications, including but not limited to the ERME. Data analysis and management are performed at a project and sometimes agency level, but not at a program level (Johnson et al. 2004). It is neither desirable nor feasible to centrally coordinate all data collection activities. However, application of pertinent data to the evaluation of the ERME will be facilitated by the organization of a coordinated collaborative information network that includes the following elements:[1]

- Incorporation of data produced by existing programs and information systems to avoid duplication of effort.
- Establishment of an estuary MR&E information-sharing committee that includes technical representatives of action agencies, the Lower Columbia River Estuary Partnership, and other entities involved in implementation and monitoring. This information-sharing committee would complement corresponding groups of policy representatives responsible for implementation.
- Integration with other basinwide MR&E groups, including the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) and the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP).
- Regular written project-level reporting by MR&E partners.
- A coordinated system for peer review of project plans and reports.

[1] Adapted from Johnson et al. (2003) and Lower Columbia River Estuary Partnership (2004b).

- Periodic estuary MR&E workshops to present new data, discuss findings, and exchange information on future plans.
- Establishment of a central, Web-accessible repository and library for estuary data and references.
- Guidelines for metadata standards to facilitate data exchange and application.
- Centrally facilitated program-level review for comprehensive synthesis and evaluation of pertinent information relative to the goals and objectives of this plan.
- Periodic program-level summary reports.
- Consistent participation and funding commitments by partners.

Next Steps

Monitoring, evaluation, and research elements identified in the draft *Federal Columbia River Estuary Research, Monitoring, and Evaluation Program* (Johnson et al. 2006) provide a consistent methodology that complements the actions identified in Chapter 5 of the estuary recovery plan module. Over the next several years, as actions identified in the module are implemented, it will be important to further integrate monitoring and research activities to ensure that recovery actions are achieving the desired results and that key uncertainties are further explored.

CHAPTER 7

Perspectives on Implementation

A substantial financial investment is being made in the Columbia River basin to recover wild chinook, coho, steelhead, and chum. How much of this investment should be made in the estuary? How much do the estuary, plume, and nearshore environments contribute to the survival of upstream ESUs, and is recovery of upstream ESUs possible without a healthier estuary ecosystem? If not, what does the information in Chapters 3, 4, and 5 tell us about which management actions to implement in the estuary?

Chapter 7 explores issues related to the selection of management actions to be implemented in the estuary and how those choices will shape future conditions for salmonids in the estuary, plume, and nearshore.

Putting the Estuary in Context

This recovery plan module reflects current scientific understanding that the Columbia River estuary, plume, and nearshore provide critical habitat that wild salmonids need to complete their life cycles. Historically, juveniles from hundreds of distinct salmonid populations, at various life history stages, used the estuary for refuge and rearing as they prepared physiologically for life in the ocean. Over evolutionary time populations developed life history strategies in which juveniles from different populations staggered their use of the estuary throughout the year, exploiting estuarine habitats in different ways for different lengths of time. Although the estuary posed risks to juvenile salmonids, the diversity in life history strategies allowed salmon and steelhead to take maximum advantage of estuarine resources, which offered tremendous opportunities for refuge and growth. Unlike an upstream tributary, through the year the estuary provided habitat for all of the salmonid populations in the Columbia River basin during a critical stage in their life cycles.

Over the last 200 years the ability of the Columbia River estuary to meet the needs of salmon and steelhead has been seriously compromised. There is no question about the extent of changes in the estuary: the timing, magnitude, and duration of flows do not resemble those of historical flows, access to the estuary floodplain has been virtually eliminated, sediment transport processes that depend on flows and upstream sediment sources are radically different than they were historically, water quality has degraded as a result of contamination, temperatures are approaching and sometimes exceeding lethal limits, and there have been fundamental changes at the base of the estuarine food web, with associated alterations in inter- and intra-species relationships. Given these changes, the current mortality rate for some Columbia River ESUs in the estuary may exceed 50 percent (Lower Columbia Fish Recovery Board 2004).

A central premise of this recovery plan module is that although the estuary ecosystem is degraded, it can be improved, and that a healthier estuary ecosystem would contribute meaningfully to the basinwide recovery of ESA-listed salmonids.

Factors That Influence Decision Making

Decisions about implementation would be easy if protecting and restoring salmonids were the only consideration. However, as much as we value healthy native fish runs, as a society we also value a stable economy, financial opportunity for individuals and businesses, public safety, and property rights. These values will play into decisions about which management actions to implement, as will the three factors used to evaluate the management actions in Chapter 5: cost, constraints, and potential benefits to salmonids.

Also affecting choices about implementation is scientific uncertainty. Although fisheries science has matured over the last 100 years, how salmonids interact in complex ecosystems is not well understood, and this is especially true in the estuary, plume, and nearshore. Yet we cannot wait until uncertainty has been eliminated before taking action. In the face of scientific uncertainty, then, decisions about implementing management actions will have to be made using the most current scientific information available, combined with best professional judgment. Historically, it has been a mix of science and policy choices that have guided decisions that affected the estuary; it is likely that these same forces will also determine the effectiveness of science-driven recovery efforts.

Significance of Constraints to Implementation

Not a single management action identified in Table 5-1 will be easy to implement. In one way or another, implementation of each of the 23 actions is constrained, in some cases greatly. For example, implementation of CRE-4, "Adjust the timing, magnitude, and frequency of flows," is constrained by international treaties, the need for flood control, irrigation requirements, upstream fish issues, and electrical generation. Given these constraints, returning to the historical hydrograph—or even something close to the historical hydrograph—is impossible. Yet CRE-4 is proposed as a management action because it might offer significant benefits to salmonids even if its implementation were incremental.

Understanding the nature and magnitude of constraints to the implementation of management actions is important for several reasons. First, it grounds the actions in the real world and tempers expectations for results. Second, it provides insights into the level of effort that would be required for an action to have a sizable impact on salmonid populations. Third and most important, it reveals that every proposed action in this recovery plan module has significant obstacles to implementation.

Because it will be difficult to implement any single action fully and gain all of its potential benefit to salmonids, it will be important to implement a relatively large number of the proposed management actions. In other words, if each management action in the estuary has significant constraints, it may take partial implementation of all or most of the actions to improve the health of the estuary ecosystem to the point that the ecosystem provides the benefits that salmonids need to recover.

To illustrate the relative constraints of different actions, Table 7-1 presents management actions by degree of constraint to implementation, in descending order.

TABLE 7-1
Management Actions Sorted by Degree of Constraint

#	Action	Degree of Constraint
CRE-02	Modify/mitigate hydro operations to reduce reservoir heating.	5
CRE-04	Adjust the timing, magnitude, and frequency of flows.	5
CRE-05	Mitigate sediment entrapment in reservoirs.	5
CRE-18	Reduce shad abundance.	5
CRE-19	Prevent invertebrate introductions.	5
CRE-10	Breach or lower dikes and levees.	4
CRE-12	Reduce vessel wake stranding.	4
CRE-14	Reduce predation by pinnipeds.	4
CRE-17	Redistribute cormorants.	4
CRE-21	Identify and reduce sources of pollutants.	4
CRE-22	Monitor and restore contaminated sites.	4
CRE-03	Establish legal instream flows.	3
CRE-11	Reduce over-water structures.	3
CRE-15	Reduce noxious weeds.	3
CRE-16	Redistribute Caspian terns.	3
CRE-01	Protect/restore riparian areas.	2
CRE-09	Protect remaining high-quality off-channel habitat.	2
CRE-06	Use dredge materials beneficially.	2
CRE-07	Reduce entrainment/habitat effects of dredging.	2
CRE-08	Remove pile dikes.	2
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and catfish.	2
CRE-20	Implement pesticide/fertilizer BMPs.	2
CRE-23	Implement stormwater BMPs.	2

Another useful table when considering implementation constraints is Table 5-3, which shows the differences in potential benefit to salmonids if actions are implemented fully, which is unrealistic, versus partially, which represents what may actually be possible. However, although Table 5-3 demonstrates the size of the gap between full implementation and constrained implementation of actions, it does not adequately characterize the magnitude of response that might be expected from constrained implementation. The next section of this document is intended to help show the potential benefit from constrained implementation of actions.

Management Actions Offering the Greatest Survival Benefits

If we were to increase our financial investment in restoration of the Columbia River estuary by an order of magnitude, what would the ecological return on that investment be? Our ability to answer that question is limited by a lack of understanding of how much mortality actually occurs in the estuary, plume, and nearshore. Still, we do have some information about potential gains that reasonably could be expected as a result of such a large investment.

Juvenile Survival Improvement. In Chapter 5, survival improvement targets were developed as a tool for comparing the potential benefits of different management actions. This planning exercise used the best available information about estuary mortality for wild, ESA-listed stream- and ocean-type juveniles and then established a 20 percent survival improvement target for the 22 management actions. The survival improvement targets were then allocated across the various management actions to help characterize where survival gains might occur. The results are conjecture and are not intended to represent a deterministically based analysis; however, the numbers do reflect information in the scientific literature, especially about mortality resulting from terns, cormorants, ship wake stranding, contaminants, and pinnipeds.

Tables 7-2 and 7-3 summarize the results of this planning exercising, sorting actions by their potential to improve survival of stream- and ocean-type juveniles, respectively, assuming that implementation of the actions is constrained. This ordering is simply an exercise to hypothesize where survival improvements equal to 20 percent of the number of juveniles exiting the estuary and plume might be expected for stream-type salmonids and ocean-type juveniles.

For stream-type salmonids, the following observations can be made from Table 7-2:

- Approximately 50 percent of the survival improvements are assigned to addressing predation by Caspian terns and double-crested cormorants.
- Approximately 25 percent of the survival improvements are assigned to major ecosystem drivers such as flow improvements, protection of riparian areas, and breaching or lower dikes to provide access to off-channel habitats.
- Approximately 25 percent of the survival improvements are assigned across the remaining actions, with varying degrees of improvements.

For ocean-type salmonids, the following observations can be made from Table 7-3:

- Approximately 70 percent of the survival improvements are assigned to the top five actions, which include protection and restoration of off-channel habitat, flow improvements, restoration of contaminated sites, and reducing sources of pollutants.
- Approximately 16 percent of the survival improvements are assigned to protecting and restoring riparian areas, reducing high temperatures, and removing pile dikes.
- Approximately 14 percent of the survival improvements are assigned across the remaining actions, with varying degrees of improvements.

TABLE 7-2
Management Actions Sorted by Benefit to Stream-type Juveniles

#	Action	Survival Target (Stream Types)	Percentage of Target Improvements
CRE-16	Redistribute Caspian terns.	450,000	~50%
CRE-17	Redistribute cormorants.	350,000	
CRE-04	Adjust the timing, magnitude, and frequency of flows.	250,000	~25%
CRE-01	Protect/restore riparian areas.	100,000	
CRE-10	Breach or lower dikes and levees.	100,000	
CRE-22	Monitor and restore contaminated sites.	90,000	~25%
CRE-09	Protect remaining high-quality off-channel habitat.	80,000	
CRE-21	Identify and reduce sources of pollutants.	80,000	
CRE-02	Modify/mitigate hydro operations to reduce reservoir heating.	50,000	
CRE-08	Remove pile dikes.	35,000	
CRE-03	Establish legal instream flows.	20,000	
CRE-20	Implement pesticide/fertilizer BMPs.	18,000	
CRE-15	Reduce noxious weeds.	15,000	
CRE-23	Implement stormwater BMPs.	12,000	
CRE-06	Use dredge materials beneficially	12,000	
CRE-05	Mitigate sediment entrapment in reservoirs.	5,000	
CRE-11	Reduce over-water structures.	4,000	
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and catfish.	3,000	
CRE-18	Reduce shad abundance.	2,000	
CRE-19	Prevent invertebrate introductions.	2,000	
CRE-12	Reduce vessel wake stranding.	1,000	
CRE-07	Reduce entrainment/habitat effects of dredging.	1,000	
	Total:	1.68 million	

TABLE 7-3
Management Actions Sorted by Benefit to Ocean-type Juveniles

#	Action	Survival Target (Ocean Types)	Percentage of Target Improvements
CRE-10	Breach or lower dikes and levees.	400,000	~70%
CRE-04	Adjust the timing, magnitude, and frequency of flows.	350,000	
CRE-09	Protect remaining high-quality off-channel habitat.	350,000	
CRE-22	Monitor and restore contaminated sites.	350,000	
CRE-21	Identify and reduce sources of pollutants.	300,000	
CRE-01	Protect/restore riparian areas.	150,000	~16%
CRE-02	Modify/mitigate hydro operations to reduce reservoir heating.	140,000	
CRE-08	Remove pile dikes.	100,000	
CRE-12	Reduce vessel wake stranding.	60,000	~14%
CRE-15	Reduce noxious weeds.	50,000	
CRE-03	Establish legal instream flows.	50,000	
CRE-11	Reduce over-water structures.	50,000	
CRE-23	Implement stormwater BMPs.	50,000	
CRE-20	Implement pesticide/fertilizer BMPs.	40,000	
CRE-06	Use dredge materials beneficially	20,000	
CRE-07	Reduce entrainment/habitat effects of dredging.	10,000	
CRE-19	Prevent invertebrate introductions.	10,000	
CRE-05	Mitigate sediment entrapment in reservoirs.	6,000	
CRE-18	Reduce shad abundance.	6,000	
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and catfish.	4,000	
CRE-16	Redistribute Caspian terns.	2,000	
CRE-17	Redistribute cormorants.	2,000	
	Total:	2.5 million	

While many of the actions are highly constrained, the planning exercise summarized in Tables 7-2 and 7-3 assumes that, even with incremental changes associated with constrained implementation, certain actions could yield significant results, especially when coupled with complementary actions. For example, ocean-type juveniles rely heavily on off-channel habitats for food sources and rearing opportunities. The two primary actions intended to improve access to off-channel habitats are CRE-10, "Breach or lower dikes and levees," and CRE-4, "Adjust the timing, magnitude, and frequency of flows." Implementation of both of these actions is highly constrained, yet they could have synergistic effects and their joint implementation—even if only partial—could result in significant survival improvements for ocean-type salmonids. In contrast, if only one of these actions were implemented (or, worse yet, neither), other actions would need to be implemented as fully as possible in an attempt to compensate for the foregone opportunity to address one of the main factors limiting juvenile salmonid performance in the estuary.

Adult Survival Improvement. Because CRE-14, "Reduce predation by pinnipeds," is the only action that directly addresses the adult life history stage of salmonids, this action is treated separately and is not included in Tables 7-2 and 7-3. Pinniped predation on spring chinook and steelhead (both stream types) at Bonneville Dam has been estimated to be approximately 3.4 percent of the salmonids arriving at the dam (U.S. Army Corps of Engineers 2006). Estimates of downstream mortality from Stellar sea lions have not been published, but unsubstantiated estimates of mortality are more than 10 percent. If applied to 2005 run returns, this rate of predation would equal about 29,000 adult spring chinook and winter steelhead (includes ESA-listed and non-listed adults). Projects to reduce pinniped predation have had limited success, and more stringent management techniques are constrained by protections afforded by the Marine Mammal Protection Act. Although the act does provide for lethal control, the process for implementing that provision is formidable. Given these constraints, CRE-14 is assigned a 17 percent reduction (approximately 5,000 fish) in pinniped-related mortality of stream-type adults annually. This is a target only and should be considered a starting place for public decision making.

Costs for Constrained Implementation of Management Actions

Estimating the cost of constrained implementation of actions is inherently speculative. This is because in many cases, the constraints to implementation have not yet been explored in enough detail to be able to determine what is and is not possible. In Chapter 5, Table 5-6 established a level-of-effort budget estimate for partial implementation of actions by assuming an optimistic view—that constraints can be reduced through focused effort and that positive changes in the estuary can be made. A more pessimistic view would likely yield a significantly lower cost estimate, with correspondingly smaller survival improvements. Costs were assigned at the project scale to help identify possible components to actions, with the expectation that future refinements would yield a more sophisticated estimate. Finally, project costs were estimated over a 25-year time horizon.

Table 7-4 organizes management actions by total estimated cost (from Table 5-6). The following observations can be made:

- Costs for the top six actions total $306 million, or about 65 percent of the entire budget. The actions include restoring contaminated sites, improving flows, reducing sources of pollutants, breaching or lowering dikes and levees, protecting off-channel habitats, and protecting and restoring riparian areas.

- Costs for the next four actions on the list equal $77 million, or about 16 percent of the budget. This group of actions consists of reducing reservoir heating, noxious weeds, vessel wake stranding, and predation by pinnipeds.
- The final 13 actions on the list equal $85 million, or about 18 percent of the budget.

There is significant uncertainty in these cost estimates because of the ambiguity about the degree to which constraints to implementation can be overcome and the level of effort that would be required to achieve a measurable result. However, it is assumed that if restoring the ecosystem of the Columbia River estuary were established as a goal, this would require financial investment on a par with that for other major ecosystem recovery efforts around the United States. Such an investment would likely exceed the $500 million cost estimate in the recovery module, over a much longer period of time—up to 50 years or more.

TABLE 7-4
Management Actions Sorted by Estimated Cost

#	Action	Cost of Action	Cost per Group of Actions
CRE-22	Monitor and/or restore contaminated sites.	$68 million	~$306 million, or 65% of total
CRE-04	Adjust the timing, magnitude, and frequency of flows.	$57 million	
CRE-21	Identify and reduce sources of pollutants.	$51.2 million	
CRE-10	Breach or lower dikes and levees.	$50 million	
CRE-09	Protect remaining high-quality off-channel habitat.	$43.75 million	
CRE-01	Protect/restore riparian areas.	$32.85 million	
CRE-02	Modify/mitigate hydro operations to reduce reservoir heating.	$25 million	~$77 million, or 16% of total
CRE-15	Reduce noxious weeds.	$21.25 million	
CRE-12	Reduce vessel wake stranding.	$17 million	
CRE-14	Reduce predation by pinnipeds.	$12.65 million	
CRE-03	Establish legal instream flows.	$10 million	~$85 million, or 18% of total
CRE-17	Redistribute cormorants.	$10 million	
CRE-23	Implement stormwater BMPs.	$10 million	
CRE-16	Redistribute Caspian terns.	$8 million	
CRE-05	Mitigate sediment entrapment in reservoirs.	$7 million	
CRE-06	Use dredge materials beneficially.	$7 million	
CRE-20	Implement pesticide/fertilizer BMPs.	$7 million	
CRE-11	Reduce over-water structures.	$5.8 million	
CRE-18	Reduce shad abundance.	$5.5 million	
CRE-07	Reduce entrainment/habitat effects of dredging.	$4 million	
CRE-08	Remove pile dikes.	$3.7 million	
CRE-19	Prevent invertebrate introductions.	$3 million	
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and catfish.	$1.05 million	
	Total:	$460.75 million	

Cost-Effectiveness of Management Actions

Cost-effectiveness is an important consideration when attempting to achieve large goals with limited resources, and the more limited the resources with respect to the goal, the more important it is that the maximum benefit be obtained from each expenditure. In the case of the Columbia River estuary, improving conditions for salmonids is likely to be an expensive and long-term effort—one that will require careful consideration of the survival benefits and costs of possible actions.

The linkage between the survival benefits and costs in this recovery plan module is difficult to characterize accurately because of the margin of error that, at this point, exists in both the estimated costs and the survival targets. Because the survival improvement targets were allocated across the set of actions as a planning exercise rather than as results of a scientific analysis, it is the allocation that is most important, not the numbers themselves. In the case of costs, estimates were made assuming that constraints to implementation of actions could be partially overcome; this assumption served as a way to explore the degree of constraints and the level of effort that would be required to bring about significant benefits to salmonids. The resulting costs should be viewed as preliminary numbers useful in starting critical discussions about decisions that will shape the future of the estuary and, to some degree, the region.

Understanding that, as outlined above, there are limitations governing the survival improvement targets and cost estimates, these sets of numbers can be compared to provide clues about which management actions might be the most cost-effective. Table 7-5 makes such a comparison, using cost information from Table 7-4 and target survival improvements from Table 7-3 to estimate the cost-effectiveness of each action, expressed as a cost/survival index. The actions are sorted in ascending order to show the most cost-effective actions first.

Table 7-5 is intended only as a general indication of cost-effectiveness, with the numbers in the table useful only in helping to frame the discussion about implementing management actions. Also, some actions were assigned very conservative survival improvement numbers because of the level of uncertainty about underlying ecological processes. This is the case with several actions related to the food web because the connection between food web changes and effects on juveniles is unclear. As a result, the cost-effectiveness ratings of these actions appear unrealistically high.

The following observations can be made from Table 7-5:

- The median of all assigned cost/survival index numbers is 139. (The median is the middle number of a group of numbers, with half the numbers having values greater than the median and half having values less than the median).
- Some of the actions that appeared most cost-prohibitive in Table 7-4, such as breaching or lowering dikes and levees (CRE-10), adjusting flows (CRE-04), and protecting off-channel habitat (CRE-9), appear cost-effective when viewed in the context of the survival improvements they could bring about. All three of these actions have a cost/survival index number above the median.
- Several actions, including redistributing terns (CRE-16), redistributing cormorants (CRE-17), and removing pile dikes (CRE-8), appear to be very cost-effective.

TABLE 7-5
Management Actions Sorted by Cost/Survival Index

#	Action	Survival (Ocean Types)	Survival (Stream Types)	Total Survival	Cost of Action	Cost/ Survival Index
CRE-16	Redistribute Caspian terns.	2,000	450,000	452,000	$8 million	18
CRE-17	Redistribute cormorants.	2,000	350,000	352,000	$10 million	28
CRE-08	Remove pile dikes.	100,000	35,000	135,000	$3.7 million	52
CRE-04	Adjust the timing, magnitude, and frequency of flows.	350,000	250,000	600,000	$57 million	98
CRE-10	Breach or lower dikes and levees.	400,000	100,000	500,000	$50 million	100
CRE-09	Protect remaining high-quality off-channel habitat.	350,000	80,000	430,000	$43.75 million	102
CRE-20	Implement pesticide/fertilizer BMPs.	40,000	18,000	58,000	$7 million	121
CRE-01	Protect/restore riparian areas.	150,000	100,000	250,000	$32.85 million	131
CRE-02	Modify/mitigate hydro operations to reduce reservoir heating.	140,000	50,000	190,000	$25 million	132
CRE-21	Identify and reduce sources of pollutants.	300,000	80,000	380,000	$51.2 million	135
CRE-11	Reduce over-water structures.	50,000	4,000	54,000	$5.8 million	135
CRE-03	Establish legal instream flows.	50,000	20,000	70,000	$10 million	143
CRE-13	Manage pikeminnow, smallmouth bass, walleye, and catfish.	4,000	3,000	7,000	$1.05 million	150
CRE-06	Use dredge materials beneficially.	20,000	12,000	32,000	$7 million	156
CRE-22	Monitor and/or restore contaminated sites.	350,000	90,000	440,000	$68 million	159
CRE-23	Implement stormwater BMPs.	50,000	12,000	62,000	$10 million	161
CRE-19	Prevent invertebrate introductions.	10,000	2,000	12,000	$3 million	250
CRE-12	Reduce vessel wake stranding.	60,000	1,000	61,000	$17 million	279
CRE-15	Reduce noxious weeds.	50,000	15,000	65,000	$21.25 million	346
CRE-07	Reduce entrainment/habitat effects of dredging.	10,000	1,000	11,000	$4 million	364
CRE-05	Mitigate sediment entrapment in reservoirs.	6,000	5,000	11,000	$7 million	636
CRE-18	Reduce shad abundance.	6,000	2,000	8,000	$5.5 million	668

In this planning exercise, the total survival improvement of actions above the median is 3.4 million juveniles (1.9 million ocean type and 1.5 million stream type), or about 16 percent of the total number of juveniles currently thought to be exiting the estuary.

Improving Ecosystem Health

The Columbia River estuary, plume, and nearshore ecosystems are degraded compared to historical conditions. One hypothesis of this recovery plan module is that if the estuary, plume, and nearshore remain in their degraded state, recovery of all 13 ESUs may not be possible. Although this hypothesis is untested, it certainly is within the realm of possibility given what is known about the mortality of salmonids in the estuary as a result of certain threats, such as Caspian terns, double-crested cormorants, and contaminants. Until this hypothesis is disproved, it would be prudent to assume that successful basinwide recovery efforts will require improvements in the health of the estuary ecosystem. The remainder of this section is intended to help characterize choices that will ultimately govern the health of the estuarine ecosystem in the Columbia River.

Is there really a problem for salmonids in the estuary? LCFRB (2004), sources such as *Salmon at River's End* (Bottom et al. 2005), and emerging micro-acoustic tagging studies make clear that the mortality rate in the estuary is very high and almost certainly approaches 50 percent for some ESUs. This alone argues for discarding the old paradigm of the estuary as primarily a transportation corridor for salmonids on their journey to the ocean. Stream- and ocean-type salmonids clearly rely on estuary, plume, and nearshore habitats for crucial rearing and refuge opportunities during one of the stages in their life cycles, and Chapters 3 and 4 of this estuary recovery module describe the mechanisms by which a degraded estuarine ecosystem puts juvenile salmonids at risk.

Is ecosystem restoration necessary in the estuary, or can we surgically reduce specific threats to improve salmonid survival? Ecosystem health in the estuary, plume, and nearshore is the cumulative result of many stressors that originate within the estuary and also outside of the estuary. The level of constraint observed in each of the management actions identified in this estuary recovery module is high, and it is extremely unlikely that one or more actions could be implemented to the degree that they would essentially eliminate a threat to salmonids. Thus each management action should be implemented to the greatest degree practical, unless it is proven that to do so would seriously undermine public safety, the economy, or property rights.

What suite of actions is most important to implement for ocean-type salmonids? There is no single correct answer to this question. In the long term, ecosystem restoration will provide the most stable, self-supporting conditions for salmonids and other native species. Ocean-type juvenile salmonids rear longer in the estuary than stream types do and therefore would benefit the most from improved ecosystem health.

The analysis and planning exercises in this recovery plan module suggest that the most important actions for ocean-type salmonids are the following:

- CRE-10: Breach or lower dikes and levees.
- CRE-04: Adjust the timing, magnitude, and frequency of flows.
- CRE-09: Protect remaining high-quality off-channel habitat.
- CRE-22: Monitor and restore contaminated sites.
- CRE-21: Identify and reduce sources of pollutants.
- CRE-01: Protect/restore riparian areas.
- CRE-02: Modify/mitigate hydro operations to reduce reservoir heating.
- CRE-08: Remove pile dikes.
- CRE-12: Reduce vessel wake stranding.

Implementing this suite of actions would cost approximately $350 million and would be expected to yield survival improvements of roughly 2.2 million wild, ESA-listed ocean-type juveniles, or 88 percent of the survival target for ocean-type salmonids. In other words, for ocean-type juveniles, 88 percent of the gain to be had from the management actions could be achieved by implementing these nine actions.

What suite of actions is most important to implement for stream-type salmonids? Stream-type salmonids prefer deeper waters with higher velocities than ocean-types do. They also reside in the estuary for shorter periods of time, but they tend to use the plume more extensively than do ocean-type salmonids. Stream-type juveniles are thought to actively feed in the estuary; new information indicates that stream types travel out of the channel to forage and may encounter predators such as the northern pikeminnow (Casillas 2006). For stream types, it is very important to reduce Caspian tern and double-crested cormorant predation. In addition, predation by pinnipeds on adult spring chinook and winter steelhead is a significant threat.

The analysis and planning exercises in this recovery plan module suggest that the most important actions for stream-type salmonids are the following:

- CRE-16: Redistribute Caspian terns.
- CRE-17: Redistribute cormorants.
- CRE-14: Reduce predation by pinnipeds.
- CRE-04: Adjust the timing, magnitude, and frequency of flows.
- CRE-01: Protect/restore riparian areas.
- CRE-10: Breach or lower dikes and levees.
- CRE-22: Monitor and restore contaminated sites.
- CRE-09: Protect remaining high-quality off-channel habitat.
- CRE-21: Identify and reduce sources of pollutants.
- CRE-02: Modify/mitigate hydro operations to reduce reservoir heating.
- CRE-08: Remove pile dikes.

Implementing this suite of actions would cost approximately $362 million and would be expected to yield survival improvements of roughly 5,000 stream-type adults (ESA-listed and non-listed adults) and 1.58 million wild, ESA-listed stream-type juveniles, or 94 percent of the survival target for stream-type juveniles. In other words, for stream-type juveniles, 94 percent of the gain to be had from the management actions could be achieved by implementing these 11 actions.

How cost-effective are the top actions for ocean- and stream-type salmonids? Of the top 11 priority actions for stream- and ocean-type salmonids, nine are at or above the median cost/survival index.

What would be gained by implementing actions that benefit both ocean- and stream-type salmonids? The lists of priority actions identified above for ocean- and stream-type salmonids contain eight actions that are predicted to benefit both types of salmonids. These actions are as follows:

- CRE-08: Remove pile dikes.
- CRE-10: Breach or lower dikes and levees.
- CRE-09: Protect remaining high-quality off-channel habitat.
- CRE-04: Adjust the timing, magnitude, and frequency of flows.
- CRE-01: Protect/restore riparian areas.
- CRE-02: Modify/mitigate hydro operations to reduce reservoir heating
- CRE-21: Identify and reduce sources of pollutants.
- CRE-22: Monitor and restore contaminated sites.

Implementing this set of actions would cost approximately $331 million and would be expected to yield survival improvements of roughly 2.92 million wild, ESA-listed juvenile salmonids (ocean- and stream-types combined). Although the majority of these would be ocean types, there is an argument to be made for favoring actions that would benefit both salmonid types—namely, that implementing such actions would be likely to provide benefits across the spectrum of life history strategies that juvenile salmonids of both types employ in the estuary. Many of the actions that benefit stream-type salmonids would also benefit ocean types displaying less dominant life history strategies, while many actions benefiting ocean-type salmonids would also benefit stream types displaying less dominant life history strategies. Actions that benefit both ocean- and stream-types, then, presumably would affect a wide range of less dominant life history strategies and thus would help preserve the diversity that contributes to salmonids' ability to persist in the face of changing environmental conditions.

However, this is not to suggest implementation only of those actions that would benefit both ocean- and stream-type juveniles because there are limitations to this approach. For instance, avian and pinniped predation actions, which would primarily benefit stream types, are cost-effective and critical to improving the survival of stream-type salmonids.

What is the schedule or critical path for implementation of actions? Table 5-2 includes a rudimentary schedule for implementation of each management action. Schedule considerations in the table are based primarily on the specific action and the timing of its component projects that depend on other projects.

At this point in estuary recovery planning, developing a critical path for the implementation of actions collectively is premature. A more reliable and refined schedule would require better understanding of the level of effort that will be applied to the estuary, and it is likely that such a schedule would correspond closely to different funding levels and key project dependencies. An important consideration concerning schedule and critical path is that it may take decades to produce measurable effects in ecosystem restoration; thus, as a schedule for implementing management actions is developed, strategies should be employed that consider short- and long-term results.

What about the lower ranking actions? In many ways, the lower ranking actions are the most difficult to characterize in terms of survival improvements and costs. This means that low ratings may be due more to a lack of scientific information than a lack of effectiveness. For example, basic changes to the food web in the estuary as a result of reservoir phytoplankton production or the introduction of invertebrates may have profound effects on the estuary, but the degree of impact is unknown. These threats must be more fully understood if their contribution to overall ecosystem health is to be determined with accuracy.

Are there other implementation factors that should be considered? Many of the management actions could have far-reaching effects if they were implemented, either because they address multiple interrelated threats, such as flow regulation and impaired sediment transport, or because their effects could compound the benefits of other, complementary management actions. An example would be the two actions of improving flows and lowering dikes and levees. Although each action by itself would increase salmonid access to off-channel habitat, implementing both actions could offer exponentially greater access, as well as contribute macrodetrital inputs to the food web and offer other ecosystem benefits. Although such benefits are difficult to quantify, the potential for synergistic effects of complementary actions is real and should be taken into consideration when management actions are selected.

Preparation for Decision Making

Chapter 7 is intended to help organize a much-needed conversation about recovery efforts in the estuary, plume, nearshore, and other ecosystems that salmonids depend on to complete their life cycles. While there are many decisions to be made, perhaps the most important is what our level of effort and commitment will be to improving conditions in the estuary. This boils down to deciding how much we are willing to do to recover salmon and steelhead in the Columbia River basin and how comfortable we are with the sacrifices that will be necessary.

The planning exercises in Chapters 5 and 7 were based on the best available science pertaining to limiting factors and threats. However, although science can help inform the key analyses in these chapters (identification of management actions, constraints evaluation, target survival improvements, and cost estimates), it cannot tell us which management actions to implement. This is partly because of the gaps in our understanding of the physical and biological world of the estuary but also because other decision-making processes are at least as important as science when it comes to making choices about the future and what we most value.

Perhaps the single most important conclusion that can be made about the prioritization of management actions is that threats remain threats to salmonids because tough choices have yet to be made—choices that are difficult because of the myriad conflicting goals of the various public, private, individual, and organizational interests within the Columbia River basin. The variety and extent of those interests are reflected in the high degree of constraint for each of the 23 management actions identified in the recovery plan module. The take-home message from this is that the estuary, plume, and nearshore are crucial to ocean- and stream-type salmonids and that achieving a meaningful boost in survival from these ecosystems will require a major investment and the partial implementation of all 23 management actions, to the extent possible.

CHAPTER 8
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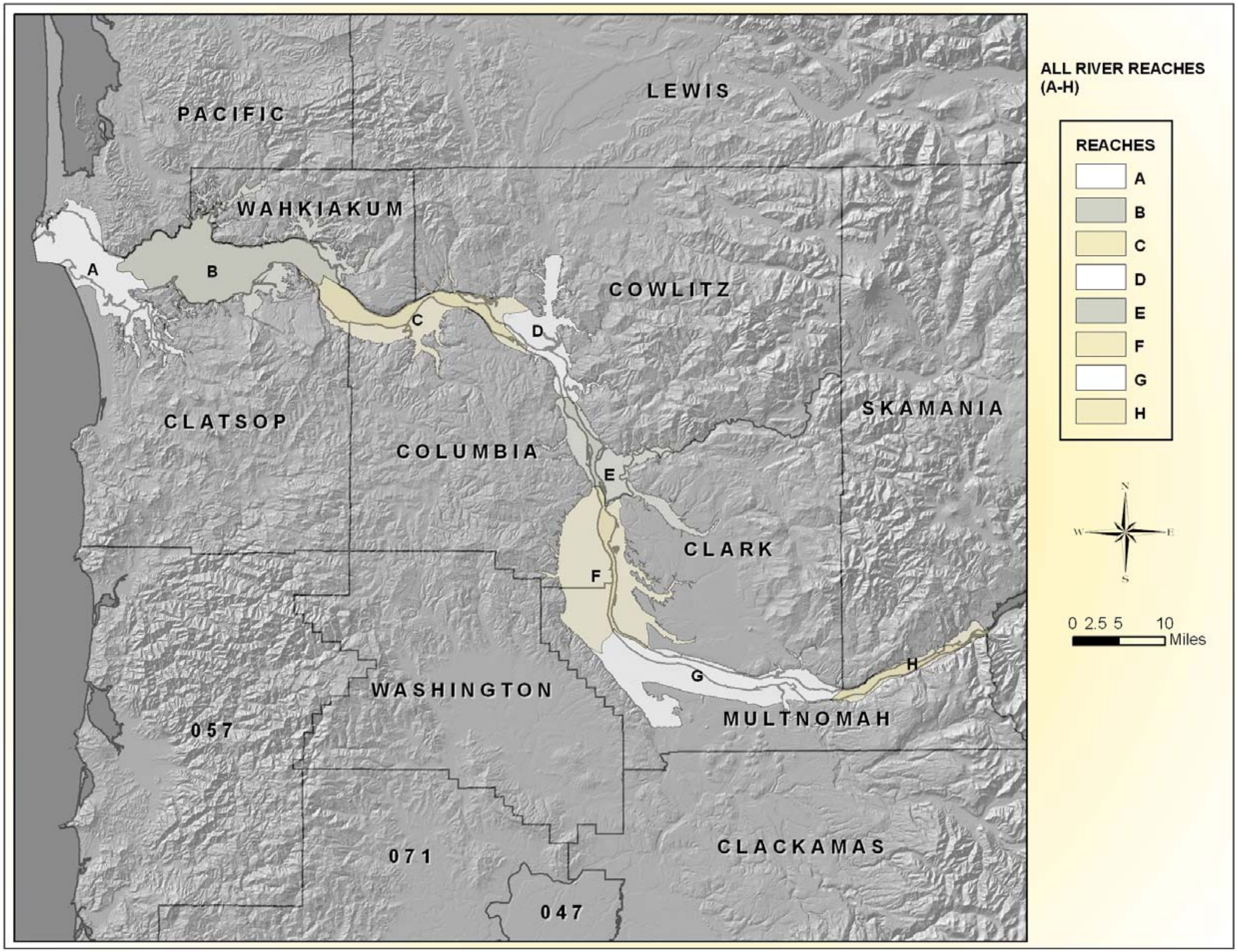
APPENDIX A

Selected Threats to Salmonids by Reach


ALL RIVER REACHES
(A-H)
REACHES
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Miles
PACIFIC
LEWIS
WAHKIAKUM
COWLITZ
SKAMANIA
CLATSOP
COLUMBIA
CLARK
WASHINGTON
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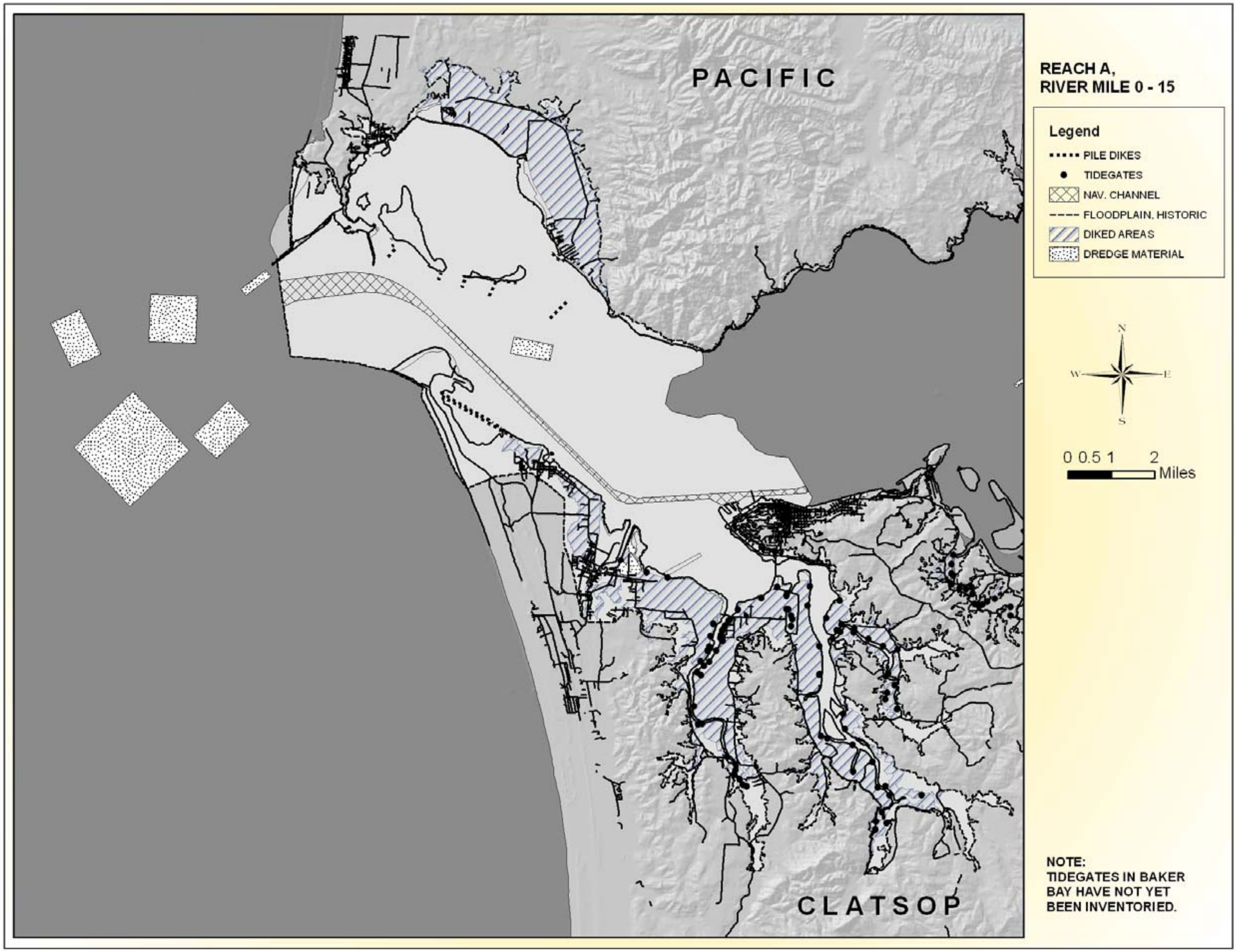
057
071
047
CLACKAMAS



PACIFIC
CLATSOP
REACH A,
RIVER MILE 0 - 15
Legend
PILE DIKES
TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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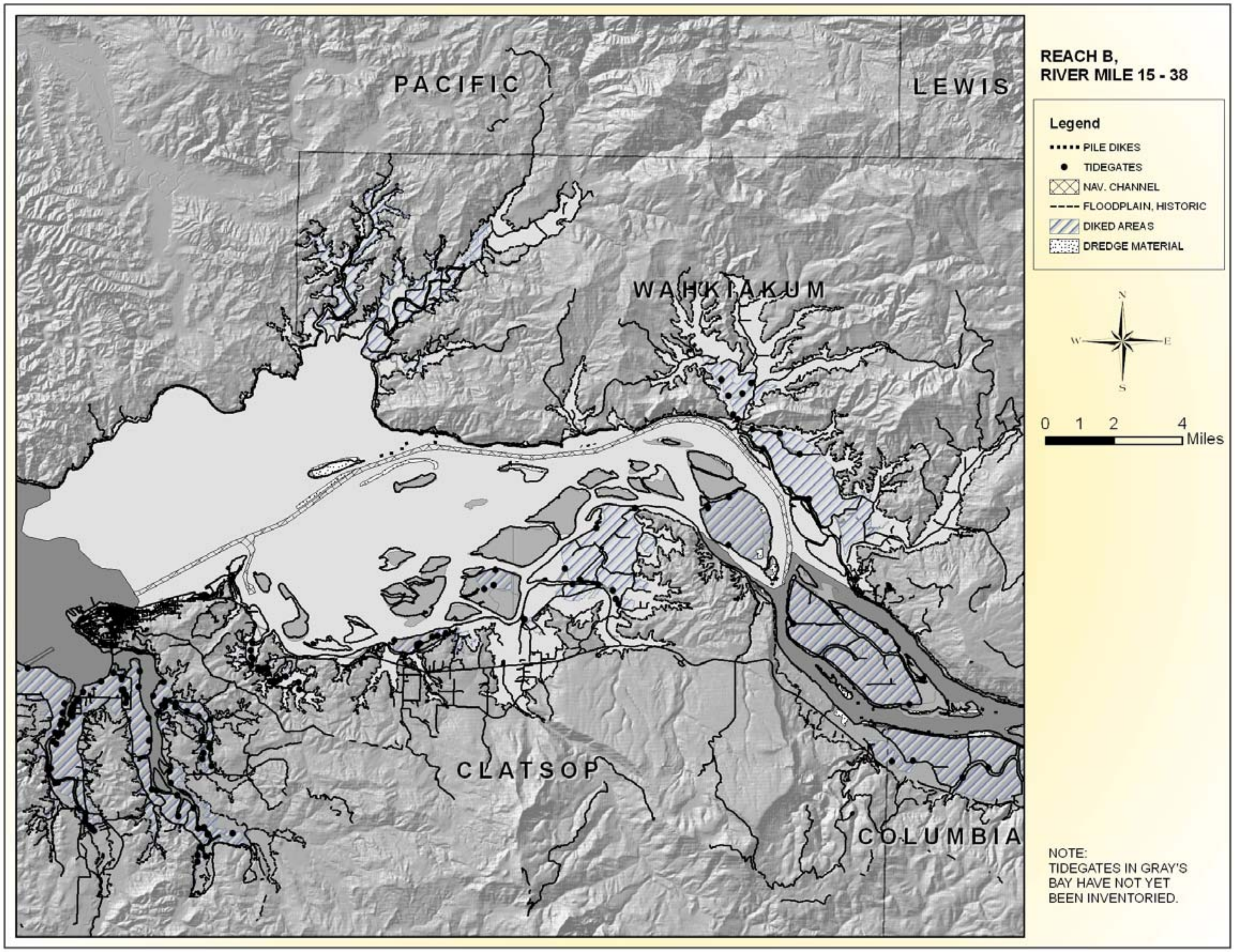
Miles
NOTE:
TIDEGATES IN BAKER BAY HAVE NOT YET BEEN INVENTORIED.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RIVER MILE 15 - 38
Legend
PILE DIKES
TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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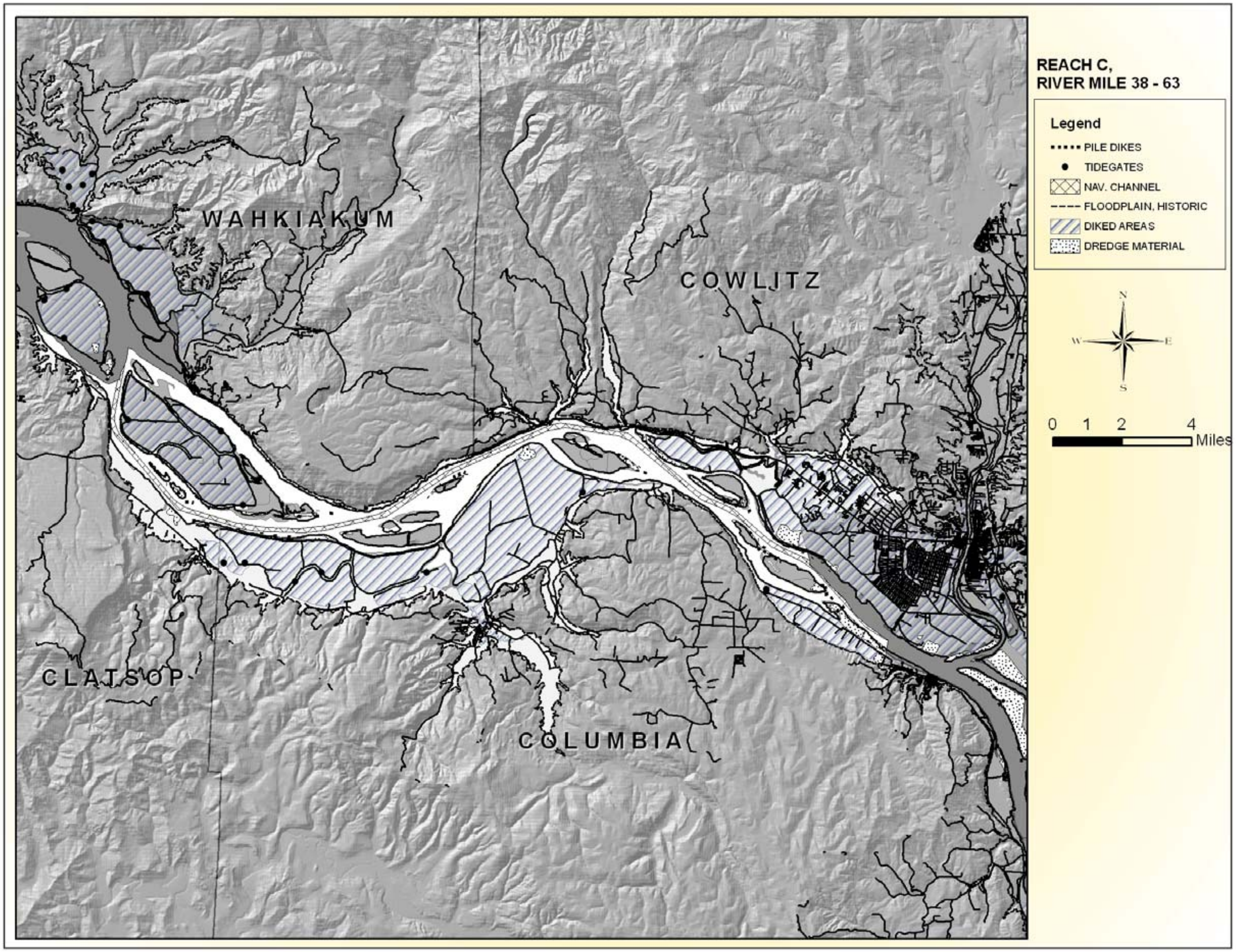
Miles
PACIFIC
LEWIS
WAHKIAKUM
CLATSOP
COLUMBIA
NOTE:
TIDEGATES IN GRAY'S
BAY HAVE NOT YET
BEEN INVENTORIED.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NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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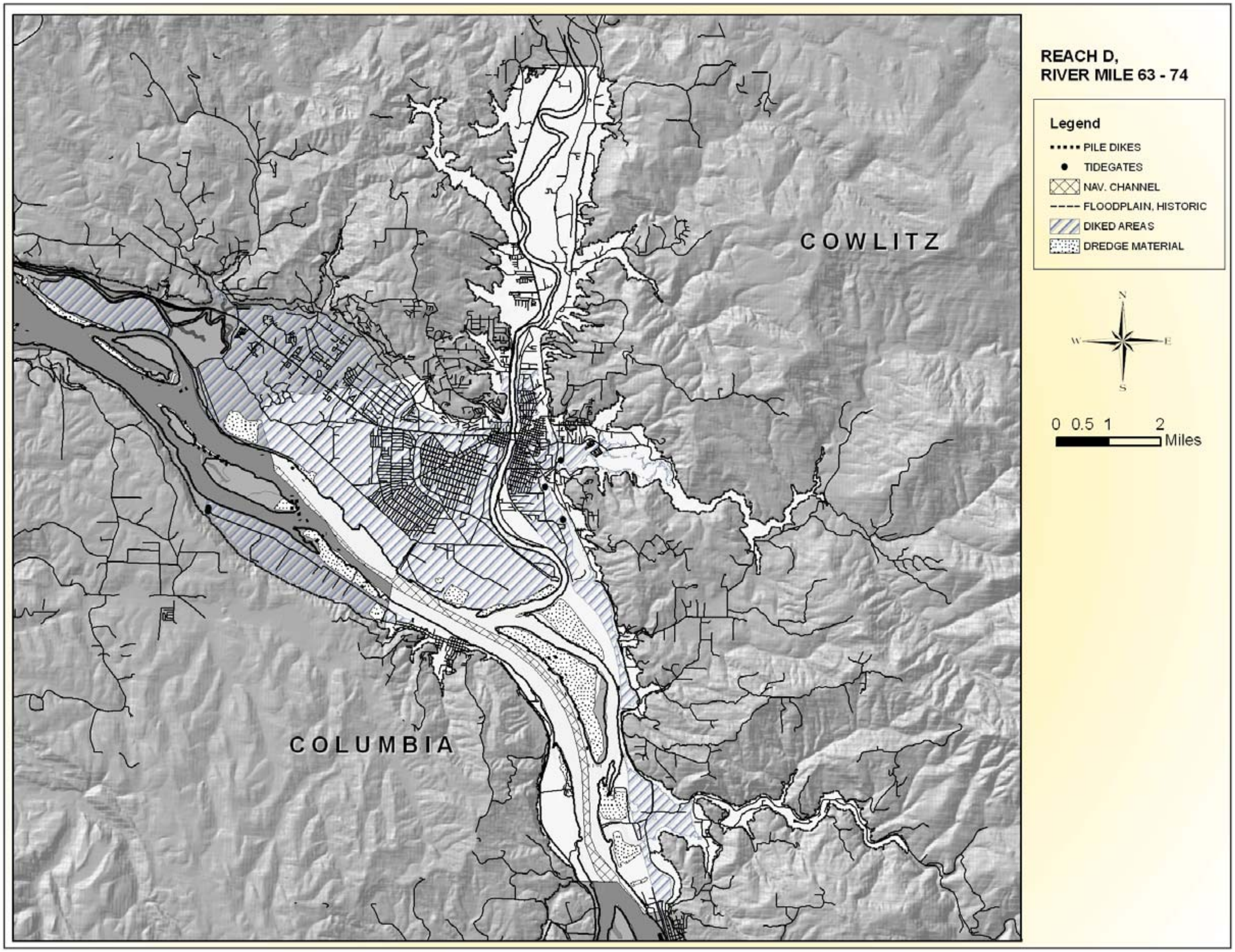
Miles
WAHKIAKUM
COWLITZ
CLATSOP
COLUMBIA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RIVER MILE 63 - 74
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TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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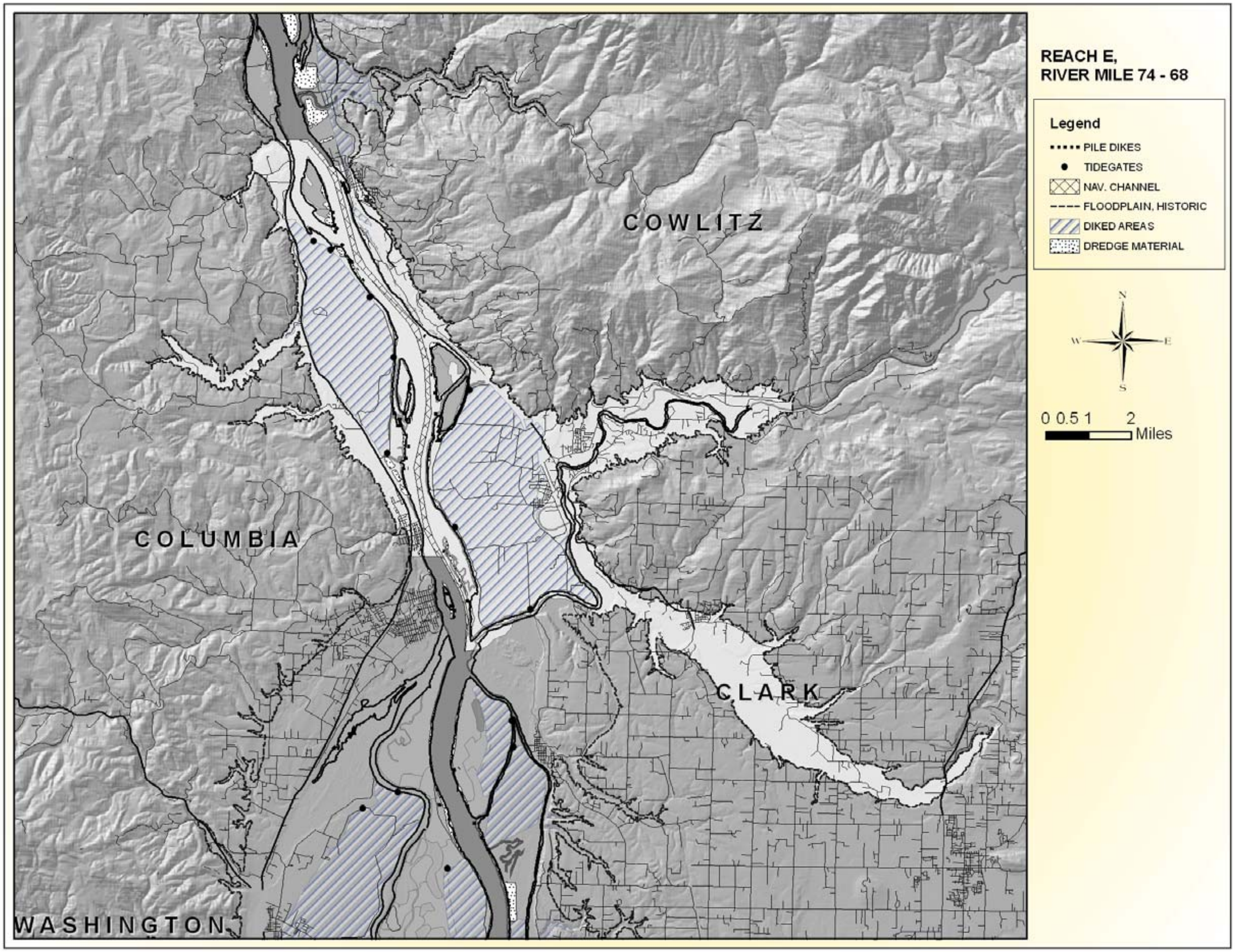
COWLITZ
COLUMBIA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TIDEGATES
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DIKED AREAS
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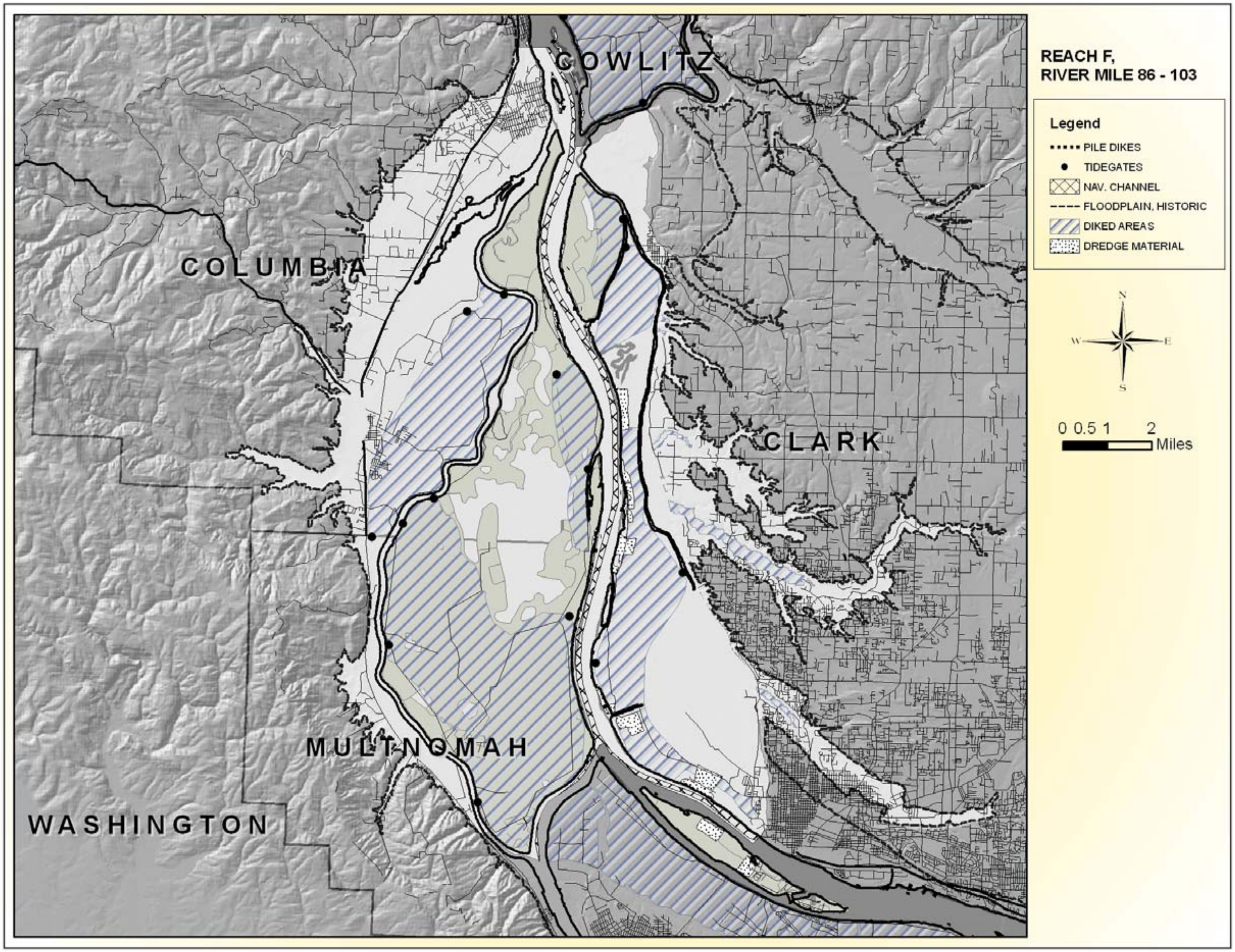
Miles
COWLITZ
COLUMBIA
CLARK
WASHINGTON


REACH F,
RIVER MILE 86 - 103
Legend
PILE DIKES
TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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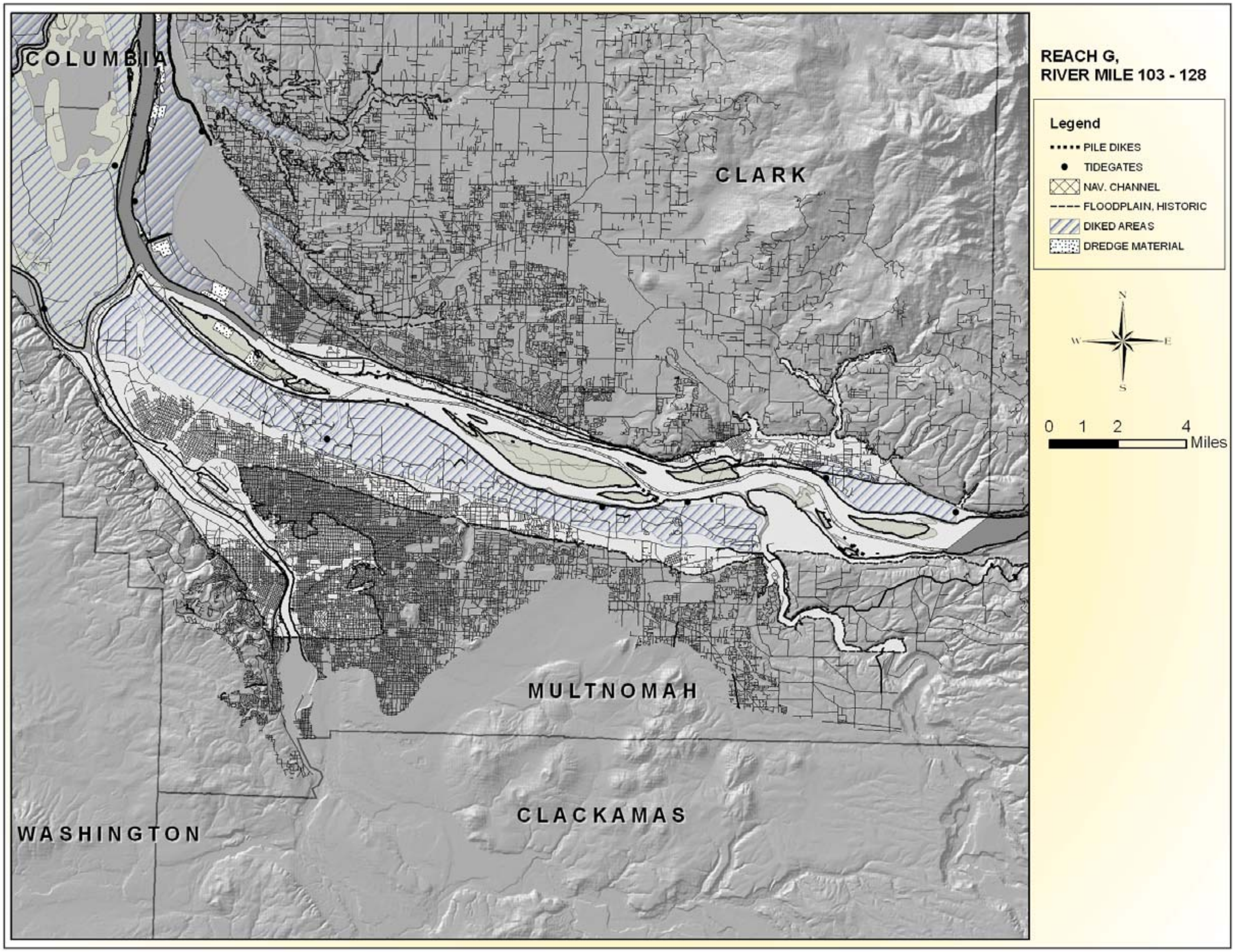
Miles
COWLITZ
COLUMBIA
CLARK
MULTNOMAH
WASHINGTON



COLUMBIA
CLARK
MULTNOMAH
CLACKAMAS
WASHINGTON
REACH G,
RIVER MILE 103 - 128
Legend
PILE DIKES
TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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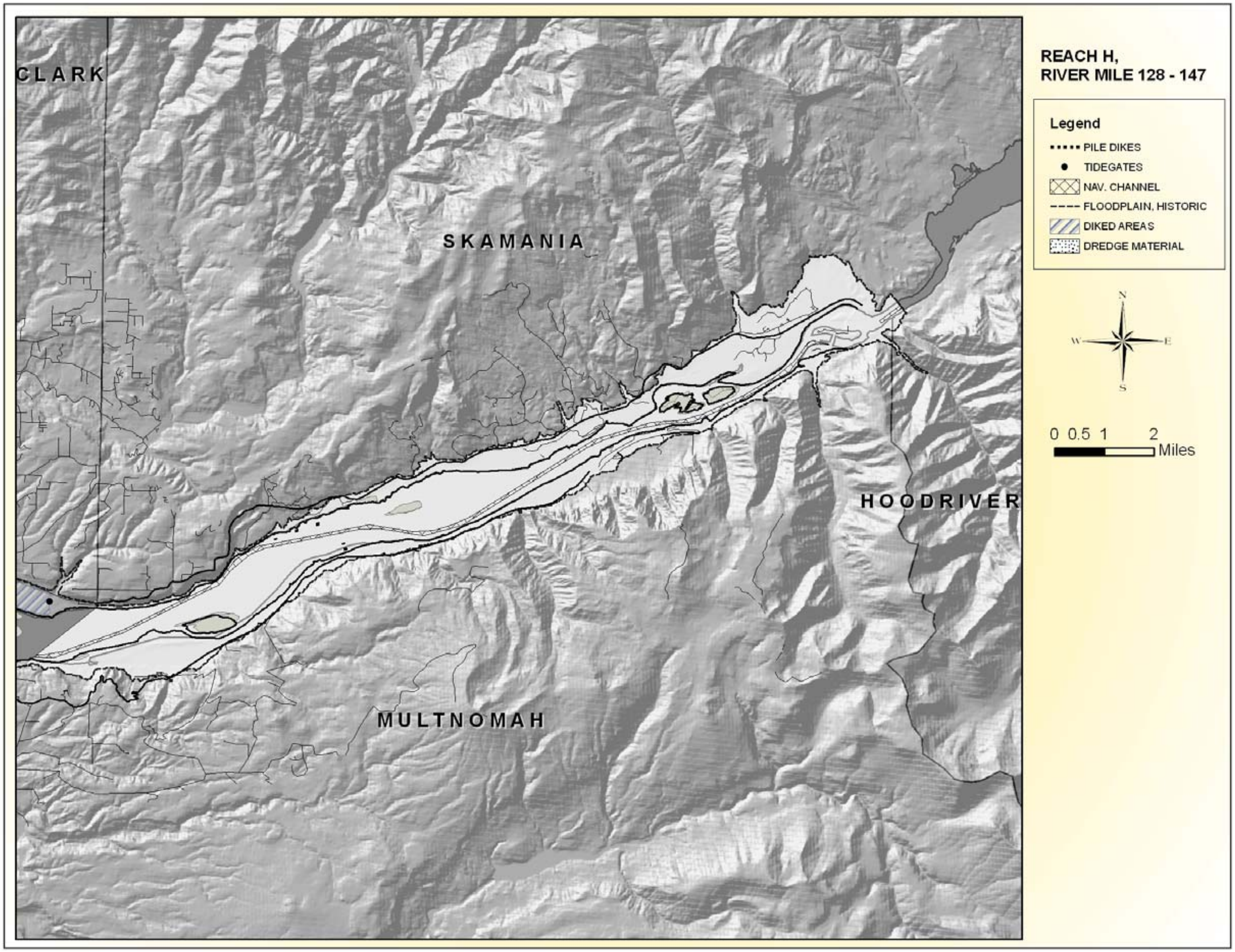
Miles


REACH H,
RIVER MILE 128 - 147
Legend
PILE DIKES
TIDEGATES
NAV. CHANNEL
FLOODPLAIN, HISTORIC
DIKED AREAS
DREDGE MATERIAL
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Miles
CLARK
SKAMANIA
HOODRIVER
MULTNOMAH

APPENDIX B

Development of Survival Improvement Targets

APPENDIX B

Development of Survival Improvement Targets

The survival improvement targets in Table 5-5 were developed as a planning tool to help initiate a comprehensive discussion about salmonid mortality in the estuary, plume, and nearshore. This tool is an important first step in setting recovery targets for salmonids in the estuary and also for the Columbia River basin. Survival improvement targets were used because, in many cases, the mortality resulting from the various limiting factors is difficult to scientifically predict. This situation is compounded by the challenges associated with estimating the degree to which management actions can reduce the threats that are the underlying causes of limiting factors. On the other hand, there are reliable estimates of mortality resulting from several of the predators, ship wake stranding, and toxic contamination, and emerging acoustic wire tagging studies are helping to estimate the extent of mortality that juvenile salmonids experience during residency in the estuary.

The following steps were used to develop the survival improvement targets:

1. The abundance of wild, ESA-listed ocean- and stream-type juveniles entering the estuary was determined using Ferguson (2006b), which estimated 25 million ocean-type juveniles and 14.3 million stream-type juveniles for 2006.
2. Several assumptions were made about overall juvenile mortality for ocean- and stream-type salmonids. An estimate of 50 percent mortality was used for ocean-type juveniles; this was generally based on emerging micro-acoustic tagging results for 2005 (35 percent mortality), plus an additional mortality (15 percent) to account for smaller ocean-type juveniles not tracked by the study. An estimate of 40 percent mortality was used for stream-type juveniles; this was based on the same micro-acoustic tagging results for 2005 (25 percent), plus an additional mortality (15 percent) presumed for deaths occurring in the plume. Continued annual study results will help refine these estimates over time.
3. For both ocean- and stream-type juveniles, a survival improvement target of 20 percent was used. The 20 percent number is not scientifically based; instead, it represents a planning target that will require refinement as the ability of actions to be implemented becomes clearer.
4. Survival improvement numbers attempt to reflect wild, ESA-listed fish only. In most cases, known mortality to salmonids (such as from terns) does not break out wild fish from hatchery fish or ESA-listed fish from non-listed fish.
5. The two targets described above were allocated across 22 actions (CRE-14, "Reduce predation by pinnipeds," was treated separately for adult mortality) by PC Trask & Associates based on an extensive literature review and personal communication with various agency staff. Each action was evaluated using limiting factor information from Chapter 3, threat information from Chapter 4, and action evaluations from Chapter 5. As a result, the allocation may be more appropriately thought of as a combination of factors, including the magnitude of the limiting factor, the degree of the associated threat(s), how well the action addresses the threat, how constrained implementation of

the action is likely to be, and the assumption that a considerable level of effort will be applied to implementing each action.

6. Survival improvement targets were assigned on a relative scale across all of the actions. As a result, the survival improvement targets should not be considered absolute in terms of a numerical result of each action, but rather a relative indication of the importance of each action. In cases where mortality was known about a particular limiting factor and a management plan demonstrated mortality reduction goals, such as with predation by Caspian terns, these numbers were used to the degree possible.

7. Survival improvement targets are intended to be correlated with cost estimates presented in Table 5-6 for constrained implementation of the management actions. The resulting cost/survival estimates (see Table 7-5) are intended to initiate discussions about the validity of cost estimates and potential survival improvement targets; the cost/survival index values in Table 7-5 are highly uncertain because of the gross assumptions on both sides of the equation.

Disclaimer: Survival improvement numbers are for illustration only and are intended to demonstrate social choices in the face of significant uncertainty. Literature sources generally do not prescribe actions, and relatively few actions have been specifically evaluated for associated survival estimates.

TABLE B-1
Notes on Development of Survival Improvement Targets

Action	Notes
CRE-1: Protect/restore riparian areas.	Estimate is unsupported in the literature. Estimate was assigned a high value in recognition of its importance relative to food sources and shoreline habitats. This is a protection action that is intended to reduce the potential for increased threat over time.
CRE-2: Modify/mitigate hydro operations to reduce reservoir heating.	Estimate is unsupported in the literature. Estimate was assigned a relatively high value because temperatures commonly exceed 19 degrees Celsius and are doing so more frequently and for longer periods of time. (Nineteen degrees Celsius is considered the upper range of survival for salmonids). Estimate is based on a relatively large level of effort to reduce the threat. It is likely that mitigation will be required in tributaries to implement the action.
CRE-3: Establish legal instream flows.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. Estimate is closely aligned with CRE-4 and probably has overlapping benefits.

CRE-4: Adjust the timing, magnitude, and frequency of flows.	Estimate is unsupported in the literature. The action affects nearly every facet of estuary ecosystem health. Estimate is intended to demonstrate that changes to the hydrograph are possible and that small increments of change may produce a significant survival improvement. This action is worthy of further analysis that may help support a more defensible survival estimate.
CRE-5: Mitigate sediment entrapment in reservoirs.	Estimate is unsupported in the literature. Estimate was assigned a low survival improvement because of the high degree of uncertainty about its potential to improve salmonid survival. Entrapment of sediment may have significantly larger effects.
CRE-6: Use dredged materials beneficially.	Estimate is unsupported in the literature. Estimate was assigned a low survival improvement because of the high degree of uncertainty about its potential to improve salmonid survival. Currently, beneficial uses are most often associated with nearshore erosion management, and little is known about potential benefits to salmonids in the nearshore.
CRE-7: Reduce entrainment/ habitat effects of dredging.	Estimate is unsupported in the literature. Estimate is relatively low because of the uncertainty and lack of mortality documentation associated with entrainment.
CRE-8: Remove pile dikes.	Estimate is unsupported in the literature. Estimate is relatively high because of the number of pile dikes in the estuary and the suspected predation effects that result from the threat, including predation by cormorants, pikeminnow, bass, walleye, and catfish. Altered flow circulation is also a threat.
CRE-9: Protect remaining high-quality off-channel habitat.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. The high estimate reflects the magnitude of importance that off-channel habitats represent to juveniles, especially ocean types. Because restoration activities are highly constrained, it is vital not to lose additional functioning habitats. Protection alone will only help preserve the status quo.
CRE-10: Breach or lower dikes and levees.	Estimate is unsupported in the literature. Estimate is intended to demonstrate that dike or levee breaching is one of the top few actions that will increase ocean-type survival in the estuary. If substantial improvements for ocean-type life histories in the estuary are to occur, this is one of a handful of actions that must be implemented. Estimate assumes a significantly higher level of implementation than what is currently occurring.
CRE-11: Reduce over-water structures.	Estimate is unsupported in the literature. Estimate is relatively high because of the number of over-water structures in the estuary and the suspected predation effects that result from the threat, including predation by cormorants, pikeminnow, bass, walleye, and catfish. Other effects, such as decreased light penetration, are not well understood.

CRE-12: Reduce vessel wake stranding.	Mortality estimates for test sites have demonstrated a wide range of confirmed mortality. In Bauersfeld (1977), an assessment of five test sites estimated approximately 150,000 stranded juveniles (on those sites). No estuary-wide estimates have been developed. The emerging availability of LIDAR imagery for the estuary may provide for analysis to extrapolate confirmed site-specific information to estuary-wide predictions. Estimate is relatively high within the range of study estimates.
CRE-13: Manage pikeminnow, smallmouth bass, walleye, and catfish.	Estimate is unsupported in the literature. Some information exists about predation rates. The threat does not currently appear to be on the increase. Estimate is relatively low, but the threat should be studied further and monitored over time.
CRE-14: Reduce predation by pinnipeds.	An estuary-wide mortality estimate is unsupported in the literature. Estimates are for adults only. Annual counts at Bonneville Dam indicate between 0.4 percent and 3.4 percent mortality of spring chinook and winter steelhead. A 500-pound Stellar sea lion consumes about 40 to 60 pounds of fish each day. An unsubstantiated estimate of all pinniped predation in the estuary of approximately 10 percent of spring chinook and winter steelhead is probably reasonable.
CRE-15: Reduce noxious weeds.	Estimate is unsupported in the literature. Noxious weeds alter food webs and habitat and work at the ecosystem scale. Very little is understood about the connection between noxious weeds and juvenile salmonid survival. Estimate is relatively high for noxious weeds compared to other ecosystem-scale threats because, although associated actions are difficult, they have a greater likelihood of success than do actions to address other similar threats, such as invertebrate infestations.
CRE-16: Redistribute Caspian terns.	Estimate is supported by the literature. Recent successes in relocating terns have been documented. Efforts to implement the action are under consideration. Estimated mortality attributed to Caspian tern predation is approximately 3.6 million juveniles in 2005. Current planning calls for a two-thirds reduction in the East Sand Island nesting.

CRE-17: Redistribute cormorants.	Estimate is supported by the literature. Efforts to manage cormorants are not nearly as mature as efforts to manage terns. There is less certainty about implementation potential because cormorants have not responded to management efforts to the degree that terns have. Estimated mortality attributable to predation by double-crested cormorants is considered to be comparable to that of predation by terns. Assignment of the target survival improvement was lower than for terns because cormorants may be harder to manage than terns.
CRE-18: Reduce shad abundance.	Estimate is unsupported in literature. Estimate is low because of the high degree of uncertainty about the relationship between shad, salmonids, and ecosystem health. Estimate is also low because the literature does not identify potential actions to reduce shad abundance levels.
CRE-19: Prevent invertebrate introductions.	Estimate is unsupported in the literature. Extent of the threat is well-documented; however, invertebrate infestations occur at the ecosystem scale, and the degree of mortality that occurs because of food web changes at this scale is unknown. Estimate is relatively low because of the uncertainty of the threat and the inherent challenges of reducing the threat.
CRE-20: Implement pesticide/fertilizer BMPs.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 3 percent to 18 percent, depending on the amount of time juveniles spend in the estuary. Estimates for CRE-21, CRE-22, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-21: Identify and reduce sources of pollutants.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 3 percent to 18 percent. Estimates for CRE-20, CRE-22, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-22: Monitor and restore contaminated sites.	Emerging literature (Loge et al. 2005) hypothesizes that mortality resulting from estuary contamination ranges from 3 percent to 18 percent. Estimates for actions CRE-20, CRE-21, and CRE-23 form the basis for survival improvements (using estimates from Loge et al. 2005).
CRE-23: Implement stormwater BMPs.	Estimate is unsupported in the literature. This is a protection action that is intended to reduce the potential for increased threat. This action does not assume retrofitting of existing stormwater function.